AERO
NGINEERING

A COMPREHENSIVE WORK FOR THOSE ENGAGED IN THE PRODUCTION, ASSEMBLY, TESTING MAINTENANCE, AND OVERHAUL OF AIRCRAFT

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VOLUME I—PART I

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The Index to the subject-matter contained in this volume will be found at the end of Volume III.

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INDEX TO DATA SHEETS FOR THE COMPLETE WORK

AERO ENGINEERING

INTRODUCTION

THE Aeroplane Industry is one which during the past two decades has suffered many vicissitudes. After long and persevering work it has now arrived at the stage where almost every manufacturer has as much work as he can cope with.

The Air Expansion Scheme has given a great fillip to the industry, and it is not unreasonable to expect that the rapid development which is now taking place in connection with Military Aircraft will be followed or accompanied by a gradually expanding market for civil types.

The production of airframes and aero engines, and the many different types of equipment which are used in the modern aeroplane, require a highly specialised type of craftsmanship.

The rapid expansion of the industry is drawing into its ranks many men who hitherto have been employed in other branches of engineering or associated trades.

One of the primary objects of the present work is to provide in a convenient form for this type of engineer a comprehensive and reliable work of reference on the subject of Aircraft Construction, Production, Maintenance and Overhaul. The wide adoption of metal construction—particularly in connection with military aeroplanes—has rendered a work of this kind necessary even for those men who have been for many years associated with the Aircraft Industry.

Never before has the whole aspect of aircraft production and maintenance, from the original specification to the forty-hours' inspection schedule, been covered within the confines of a single work.

The operative in the production shops, whether engaged upon airframe construction or upon the machining, fitting, assembly or testing of aeroplanes, will find the information contained in the following pages ideally adapted to his needs.

Information on the production side has been contributed by men closely associated with this work in some of the largest aeroplane and engine factories in the country.

In fact, it is only through the courteous and cordial co-operation of so many of the large manufacturers, who realise the need for a work of this description, that we have been able to deal so thoroughly and in such a practical manner with some of the leading types of British aircraft, both from the production side and also from the point of view of the ground engineer.

Comparatively little space has been devoted in this work to the purely descriptive side of the subject. This, we believe, has already been covered very well in the excellent technical periodicals—notably *Flight*

and *The Aeroplane*—which week by week present a record of progress in the industry, whilst the popular aspect is admirably covered in *Popular Flying.*

At the same time, it has been realised that for the men who have newly entered the Aircraft Industry it is essential to have a broad survey of the underlying principles governing the design of aeroplanes and the leading types of aircraft which have been perfected during the past few years.

This information is necessary in order that the reader can obtain an intelligent view of the whole scheme in which his own activities may form a minor—though none the less important—part.

The man who merely wishes to earn a living in an aeroplane factory and who is devoid of any ambition to hold a position of responsibility in the industry will not need this comprehensive survey of modern practice.

The present work is, however, intended for those men who realise the vast potentialities of this industry and who are anxious to prepare themselves to take advantage of the opportunities which will present themselves as the expansion continues.

In compiling this work we have found that each maker of aircraft has his own methods, based upon the practical experience gained in past years. In a few cases, these processes and methods are of a more or less secret nature—but, generally speaking, we have been able to secure information and photographs which give most useful information regarding the most up-to-date practice in aircraft production, servicing, overhaul and repair.

This interchange of ideas between the leading manufacturers cannot fail to be productive of further progress.

We take this opportunity of expressing our appreciation of the assistance afforded to us by the following :—

The De Havilland Aircraft Co. Ltd.
Rolls Royce Ltd.
Hawker Aircraft Ltd.
Claudel-Hobson Carburetters Ltd.
Marconi's Wireless Telegraph Co. Ltd.
A. V. Roe & Co. Ltd.
The Bristol Aeroplane Co. Ltd.
Handley Page Ltd.
Airspeed (1934) Ltd.
The Fairey Aviation Co. Ltd.
Imperial Airways.
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Blackburn Aircraft Ltd.
Saunders-Roe Ltd.
Phillips & Powis Aircraft Ltd.
Pobjoy Airmotors & Aircraft Ltd.
Percival Aircraft Ltd.
Short Bros. Ltd.
The British Oxygen Co. Ltd.
Bendix Ltd.

In conclusion, we offer this work to practical men in the industry and to those about to enter the industry, in the hope that they will find the information not only of the greatest practical utility, but also presented in a manner which enables it to be readily absorbed.

H. N.
E. M.

ESSENTIAL REQUIREMENTS OF MODERN AEROPLANES

SECTION I—TYPES OF AEROPLANE AND DESIGN OF POWER PLANT

By H. Nelson, M.B.E., A.M.I.Mar.E.

AERO ENGINEERING involves consideration of the following:—

(a) Materials.
(b) Workshop equipment.
(c) Workshop processes.
(d) Manufacture of parts.
(e) Structures.
(f) Inspections and tests.
(g) Maintenance.
(h) Operating equipment.

Aeroplane materials, their physical and chemical properties, the effects of impurities and structural defects, the uses to which they are put and, in important instances, the essential metallurgical properties will be described.

Under the heading of workshop processes the various forming, shaping, conditioning, joining and protective operations such as seasoning, heat treatment, brazing, welding and anti-corrosive treatments, etc., are included.

Consideration of the manufacture of parts such as longerons, struts, wires, fittings, etc., is followed by the assembly of parts in the erection of an airframe.

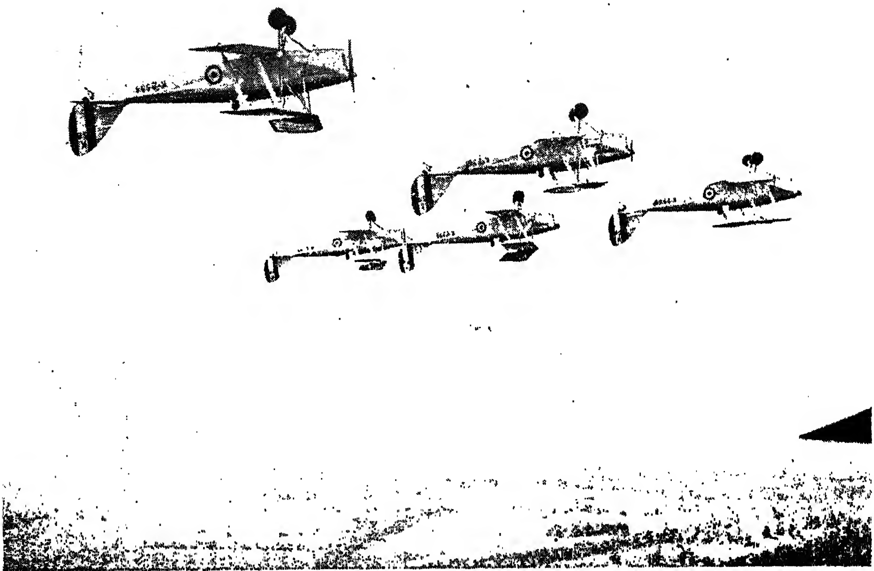
Inspections and tests will be described over the entire range from raw materials to the finished article.

The various maintenance problems including operating inspections, upkeep routine and repair procedure are dealt with in sequence.

Operating equipment such as parachutes, oxygen apparatus, etc., will be considered.

Essential Parts of an Aeroplane

An aeroplane must meet several requirements. The first is a means of keeping itself supported in the air; the wings are designed to provide lift when they are moved rapidly through the air. The second is a method of protecting the crew, passengers and load; this is met by the fuselage, nacelle or hull. The third is a power plant to give the necessary power to overcome the drag of the aeroplane through the air. The fourth is a means to enable the crew to direct the flight of the aeroplane correctly; this is fulfilled by the control surfaces. The fifth requirement is a means of supporting the aeroplane when at rest, when taking off, and when landing; this is met by the landing gear.



[*Photo : Charles E. Brown.*

Fig. 1.—DE HAVILLAND "TIGER-MOTH" TWO-SEATER TRAINING BIPLANES IN UPSIDE-DOWN FORMATION.

These aeroplanes are capable of slow landing and take-off speeds and aerobatics, as shown above.

An aeroplane is distinctive in that it must be provided with means to control it in three dimensions. It is necessary to have a rudder, elevator and ailerons to keep it on an even keel in straight flight or for varying its attitude in flight as necessary.

Vital Characteristics

The designer of an aeroplane having an engine of a known power and given loading and space requirements attempts to embody the following :—

(*a*) The lowest possible landing speed for a given wing area.
(*b*) The highest possible flying speed.
(*c*) The best rate of climb.
(*d*) The desired amount of stability.
(*e*) Good visibility.
(*f*) The best strength weight ratio.
(*g*) Minimum head resistance.

The first three characteristics depend primarily on the selection of suitable aerofoils. Stability and visibility depend largely on the design. The remaining characteristics are influenced by the selection and manufacture of structural materials.

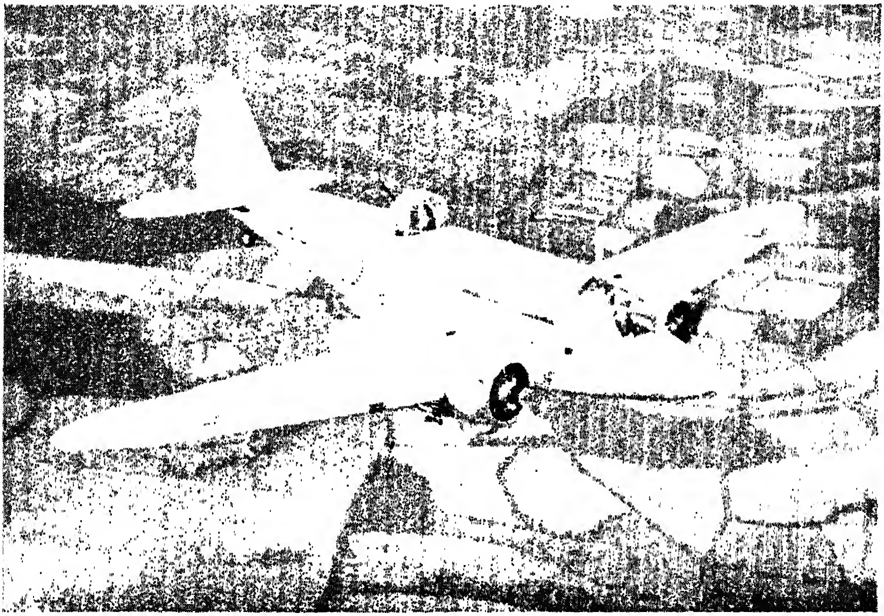


Fig. 2.—CONVERTIBLE FROM CIVIL TO MILITARY PURPOSES—THE AIRSPEED ENVOY.

This can be converted from a passenger or freight liner into a fast-medium bomber in eight hours. Note the gun turret. Supplied to the Government of the Union of South Africa for their Air Force.

Essential Structural Qualities

In addition to the performance characteristics there are structural qualities essential to successful operation. These are :—

(*a*) Sufficient rigidity to prevent vibration and distortion.
(*b*) Flexibility sufficient to absorb and distribute shocks and uneven strains.
(*c*) Parts which will show definite signs of deterioration prior to actual failure.
(*d*) Materials which are homogeneous, resistant to fatigue, etc.
(*e*) Maximum resistance to deterioration from corrosion.
(*f*) Accessibility and simplicity of repair from the power plant, airframe and equipment standpoint.

Requirements of a Successful Aeroplane

Consideration of the previous notes leads to the conclusion that a successful aeroplane must, at best, be a compromise owing to conflicting requirements. For example an aeroplane designed for ease of repair will have a greater head resistance than one in which this feature is ignored.

A successful aeroplane must, therefore, meet the undermentioned requirements in order of relative importance :—

(*a*) The design must be such that the aeroplane will best perform the functions for which it is built.
(*b*) The aeroplane must be built as cheaply and simply as possible.
(*c*) Repair and maintenance must require a minimum of expense and time.
(*d*) The aeroplane must be as far as possible aerodynamically efficient.

Classification of Aeroplanes

Aeroplanes may be classified in five general ways, *viz.*, with respect to :—

(*a*) The position of the airscrew in relation to the wings.
(*b*) The number and arrangement of the engines.
(*c*) The number and arrangement of the wings.
(*d*) The arrangement for landing and taking off.
(*e*) The purpose for which it is designed.

"Pusher" and "Tractor" Types

The first aeroplane to be successfully flown had the airscrew placed behind the wings. An engine-airscrew unit of this type is designated a "pusher." Later aeroplanes have the airscrew mounted in front of the wings and are called "tractors."

Single-, Twin- and Multi-engined Types

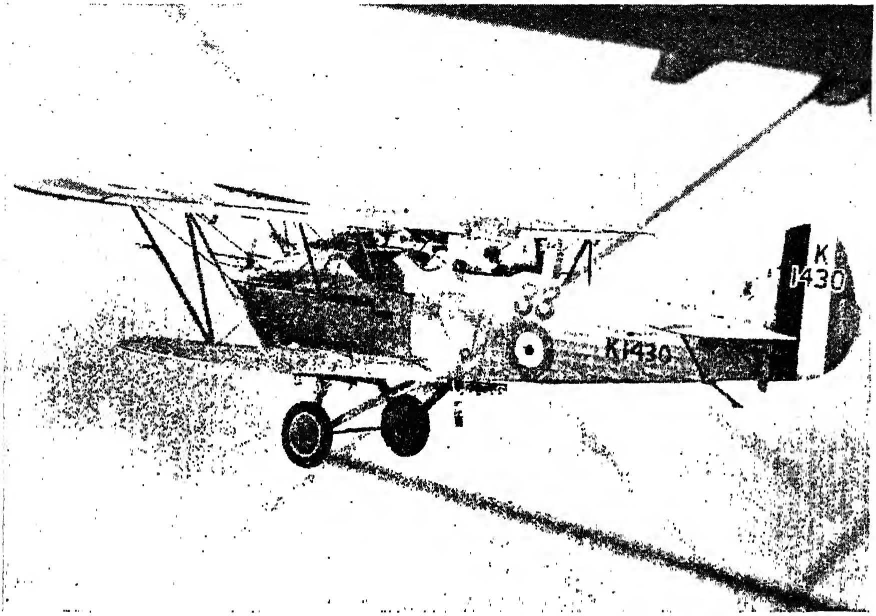
Aeroplanes are known as single-, twin- or multi-engined. They may be further designated as twin- or twin-tandem. Twin indicates that the two engines are side by side, while twin-tandem indicates that one engine is in front of the other.

Mono-, Bi- and Multi-plane Types

The monoplane is an aeroplane with only one main supporting surface or plane, sometimes divided into two parts by the fuselage. A biplane is an aeroplane with two main supporting surfaces one above the other. A triplane has three main supporting surfaces one above the other. Aeroplanes with more than two main supporting surfaces are in general termed multi-planes.

Landplane, Seaplane and Flying Boat

The lower structure of an aeroplane is designed to carry the load when on land or water. This brings about the designation land- or seaplane. Seaplanes are further characterised as the float type or boat type. In the former, one or more floats attached below the wings serve merely to support the aeroplane on the water. With the boat type seaplane,



[*Photo: by courtesy of "The Aeroplane."*
Fig. 3.—THE HAWKER HART TWO-SEATER DAY BOMBER.

usually termed the flying boat, the hull serves both as a flotation unit and also houses the crew, controls, tanks, etc.

MILITARY AEROPLANES

Duties for which they are Designed

Military aeroplanes must be of superior performance to the corresponding enemy type. The following are types required for specified purposes :—

(*a*) Fighter.
(*b*) Army or Navy reconnaissance.
(*c*) Bomber (day or night).
(*d*) Torpedo.
(*e*) Troop carriers.
(*f*) Training.

Requirements of Military Types

Military aeroplanes must embody, as far as possible, all the requirements mentioned previously, as well as those of unobstructed vision in all directions, and the installation of military equipment for efficient operation. These conditions will conflict with those for aerodynamic efficiency.

Fighters

A fighter may be either a single- or two-seater aeroplane. A single-

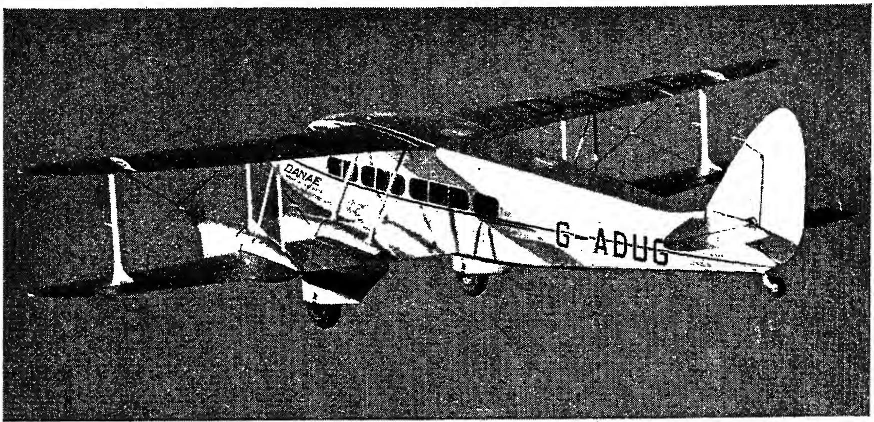
Fig. 4.—MONOPLANE FOR MILITARY AIR TRAINING.

A Miles Hawk-Major trainer supplied to the Roumanian Government for their Air Force. The maximum speed is 150 m.p.h. The training type of aeroplane has dual controls. Note the excellent field of visibility.

seater fighter is constructed for use from land or from aircraft carriers. The difference between the two types is the limit of performance due to the requirements for landing.

The landing speed of the latter type must be low enough for the arrester gear of the carrier, so that considerably higher performance can be expected from the former. The term performance covers more than merely maximum speed, which is usually accepted as the chief criterion of an aeroplane.

Speed without a high rate of climb is useless, and without manœuvrability the military advantages of speed and climb are lost. Speed, climb and manœuvrability are all made ineffective if the aeroplane has not sufficient power to enable the pilot to choose his own time and mode of attack. This calls for altitude advantage or a superior ceiling. Ability to attain an altitude advantage depends upon a high rate of climb, not merely at sea-level, but at fighting altitudes. This necessitates lighter wing loading, and the employment of supercharged engines. Without adequate vision the pilot is severely handicapped, blind spots must therefore be kept to a minimum. Guns must be placed in such a manner that jams can be cleared easily.



[*Photo :* " *Flight.*"

Fig. 5.—TEN-PASSENGER, MAIL AND FREIGHT CARRIER.
The four-engined de Havilland 86 commercial. Maximum speed 175 m.p.h.

Factors of safety must be adequate for all accelerations required of the aeroplane and controllability must be exceptional over the complete range of speed.

Army or Navy Reconnaissance

Reconnaissance aeroplanes are generally two- or three-seaters. The desirability of having reconnaissance aeroplanes operating from submarines has brought into being the single-seater reconnaissance type. The employment differs widely. The single-seater reconnaissance type to operate from a submarine must be stowed aboard, making rapid assembly and dismantling the essential requirements. The stowage facilities must necessarily be cramped owing to the limited deck space available. In consequence, a small aeroplane must be employed, with performance as to speed, ceiling and manœuvrability secondary to reliable communication and rapid assembly and dismantling features. The two-seater reconnaissance type is used primarily to increase the radius of action, or by radio communication to send information concerning the numbers, position and movements of the enemy. For proper fulfilment of its mission, blind spots must be limited as far as practicable.

Bombers (Day and Night) and Torpedo Aeroplanes

Bombers (day and night) and torpedo types are load carriers. The bomber has its bomb load together with a fuel load sufficient for the necessary range. The demands dictated by the carrying of heavy loads causes the sacrifice of so many flying qualities that offensive combat is hampered. Reliance has to be placed upon supporting fighters and upon well-disposed defensive armament.

Troop Carriers

These are load carriers and are essentially of a large type. The value of speed should not be lost sight of, in view of the possibility of contrary winds reducing their effective range.

Training

The training type is dual control, strong and reliable, capable of aerobatics and with excellent visibility. It should permit of easy installation of engines, be capable of quick assembly and dismantling and of economical upkeep. Slow landing and taking-off speeds are the primary essentials. Extreme ease and quickness of recovery to normal from abnormal attitudes of flight are essential.

The Development of the Aeroplane

Military aeroplanes involve much more than design and construction. They should be capable of mass production, be comparatively free from structural and power plant failures, and be suitable for their intended duties. Aeroplanes are therefore classed by types as experimental or service—the former being chosen—the latter are only accepted after exhaustive tests. The first aeroplane to be completed may differ in many respects from the original design. The specification is the starting point of the design. Wind-tunnel tests will require to be made on a model to ensure the performance requirements being met. Exhaustive loading tests will have to be made on various parts of the structure to verify the stress analysis and ensure that the strength requirements are met. A "mock-up" of the cockpits will probably be required to ensure economic and efficient utilisation of space. These tests may dictate various changes which may make the completed article differ radically from its original conception.

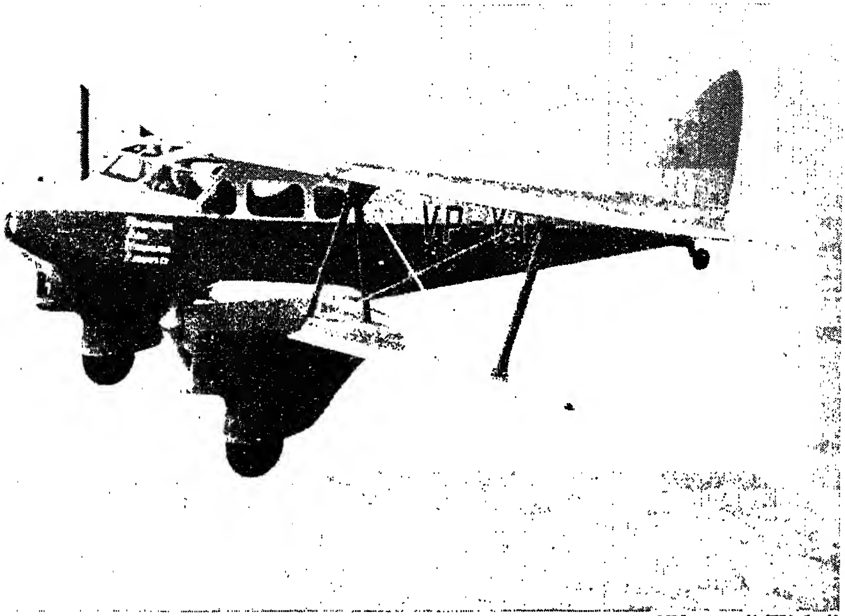
CIVIL AEROPLANES

An aeroplane is, as a rule, designed for some particular purpose. The more limited the purpose the easier the design and manufacture. If load-carrying is the purpose for which an aeroplane is required one can readily be built to carry the load. If a considerable degree of manœuvrability is required in addition its carrying capacity and stability will both suffer. If an all-purpose type is desired, it must be understood that it cannot be as satisfactory for each purpose.

Duties for which they are Designed

Civil aeroplanes must be designed to meet specific requirements. The following are the usual types :—

(a) Large type passenger.
(b) Cargo and mails.
(c) Single-seater owner-pilot.
(d) Two- or more seater owner-pilot.
(e) Two- or more seater passenger.



[Photo: "Flight."

Fig. 6.—A TWIN-ENGINED MULTI-PURPOSE BIPLANE—THE D.H. 90 "DRAGONFLY." Used for light traffic air lines, air survey, etc., with accommodation for five persons.

Requirements of Civil Types

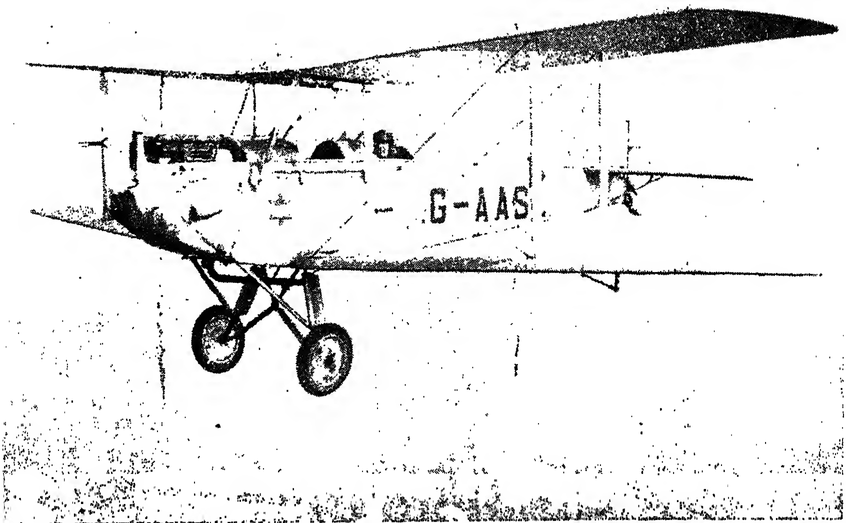
Civil aeroplanes must meet normal aerodynamic requirements. Reliability is the primary essential to which speed is a secondary consideration. The pay-load must be as large as possible in relation to operating costs. They should be designed in such a way that routine inspections can be carried out easily and effectively.

Large Type Passenger Aeroplanes

These are essentially load carriers and must carry a sufficient reserve of fuel to ensure arrival at the end of their longest intended journeys. The demands dictated by a heavy pay-load entail the sacrifice of certain flying qualities. High speed and manœuvrability must be sacrificed to a certain extent. The comfort of the passengers has also to be considered.

Cargo and Mail Types

The requirements are similar to those of large passenger aeroplanes, but speed may be considered to the slight detriment of loading and they should be designed for night flying.



[*Photo :* " *The Aeroplane.*"

Fig. 7.—TWO-SEATER LIGHT 'PLANE FOR OWNER-PILOT, CLUB AND TRAINING PURPOSES.

Single-Seater Owner-Pilot Types

The construction of these types is, to a certain extent, dictated by the requirements of the individual. In general they should be strong and reliable, capable of aerobatics and economical in upkeep. Slow landing and taking-off speeds are of importance.

Two- (or more) Seater Owner-Pilot Type

Similar to the single-seater owner-pilot type, but of heavier maximum loading.

Two- (or more) Seater Passenger Type

This type must be capable of transporting a few passengers at reasonably fast speeds to their destination, speed being considered as more important than loading for this type of aeroplane.

PERFORMANCE AND DESIGN

Performance Tests

Aeroplane performance depends to a large extent on the weight of the finished article with the equipment installed and full normal load. The completed aeroplane is weighed both empty and with full load. Performance tests then carried out consist in the determination of :—

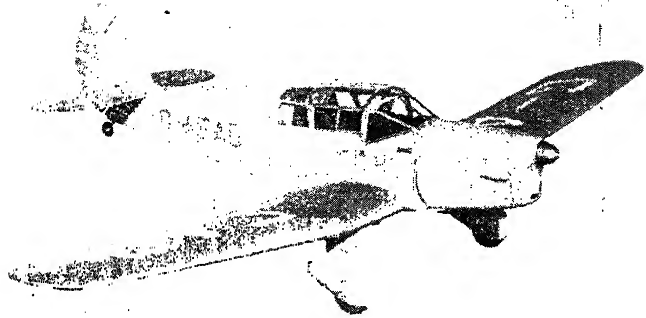


Fig. 8.—PRIVATE USE 'PLANE (PERCIVAL " VEGA GULL ").

A three-seat cabin monoplane. Flown by Miss J. Batten when she beat the England to Australia record in 5 days, 21 hours, 3 minutes. Winner of King's Cup, 1936.

(*a*) The maximum and minimum speeds in horizontal flight at various altitudes.
(*b*) The best rate of climb at various altitudes up to the aeroplane's ceiling.
(*c*) The time required to climb to various altitudes up to the ceiling.
(*d*) The ceiling or altitude at which the rate of climb drops to 100 ft. per minute.
(*e*) The absolute ceiling or altitude beyond which it cannot climb.
(*f*) The best gliding angle.
(*g*) The landing speed.
(*h*) The stability, manœuvrability and controllability.
(*i*) The taxi-ing or, if a seaplane, the rough water handling qualities.

If the specified requirements are not met, the design is altered until it is satisfactory. Careful design, wind-tunnel tests, etc., minimise the possibility of failures.

Principles of Design

In designing an aeroplane the power plant should be decided upon first. To enable the performance to be predicted the power loading,

that is, the weight to be lifted per horsepower, must be known. The following details of the power plant must be known before proceeding with the design.

(a) Weight and space occupied.
(b) Flexibility and installation.
(c) Economy.
(d) Availability.

Power Loading—Some Vital Figures

Experience over a long period has established the fact that the power loading of an aeroplane must not exceed 25 lb. per h.p. As an example, an aeroplane of 10,000 lbs. would require a power unit capable of developing a minimum of 400 h.p., otherwise performance characteristics would be sacrificed. Most aeroplanes do not approach this value. Fighter types are approximately $7\frac{1}{2}$ lb. per h.p. All development towards successful flight, such as carrying capacity, range, speed, rate of climb, ceiling and safety, calls for decrease in power loading. Engine weight per h.p. must therefore be reduced as far as possible.

How to Calculate the Power Loading

The all-up weight may be estimated closely when the engine has been selected, as follows :—

(a) The weight of fuel for the desired endurance is obtained from the fuel consumption of the engine.
(b) The weight of oil required is normally about 10 per cent. of the fuel by volume.
(c) The weight of the power plant and its accessories.
(d) The weight of the useful load, including the crew and equipment.
The above give the total weight of the aeroplane less the structure.
(e) The weight of the structure. This is usually estimated by dividing the total weight less structure by 0·70.

The total all-up weight thus obtained is divided by the normal rated h.p. of the power plant to determine the estimated power loading. The characteristics of the aeroplane may be predicted to be similar to those of an existing type with the same power loading.

√Selection of an Engine

In selecting a power plant for an aeroplane the essential requirements should embrace :—

(a) Reliability.
(b) Minimum weight per h.p.
(c) Economy in fuel and oil.
(d) Durability.
(e) Availability of spares.
(f) Low cost.
(g) High strength weight ratio.
(h) Small size.
(i) Lack of vibration.
(j) Interchangeability of parts.
(k) Speed ratio.
(l) Sustained maximum of output.
(m) Suitability for mass production.

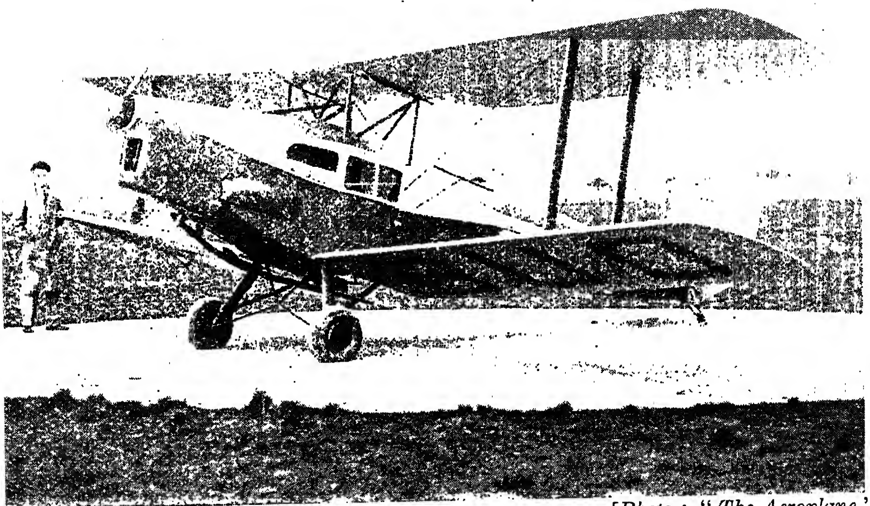


Fig. 9.—AN AIR TAXI. [*Photo : " The Aeroplane."*

Two- or three-passenger biplane for feeder routes to air liner. The " Fox Moth."

Choice Between Air- and Liquid-Cooled Engines

A point to be settled early is whether air-cooled or liquid-cooled engines are to be used. The advantages of air-cooled over liquid-cooled engines are as follows :—

(*a*) Lower weight per b.h.p. due to elimination of radiators, liquid pipes, etc.
(*b*) Parts are more accessible for repairs, due to simplicity of construction.
(*c*) No likelihood of forced landings due to liquid leaks, or boiling in hot weather.
(*d*) In military types, less vulnerability to gunfire due to elimination of liquid system.

The disadvantages are :—

(*a*) Greater frontal area which requires streamlining. This is partly counteracted by the radiator in the liquid-cooled engine.
(*b*) Less efficient cooling which limits the size of the cylinders, the mean effective pressure and the number of cylinders that may be employed.
(*c*) Slightly poorer visibility for the pilot, owing to greater frontal area.

Engine Arrangement

When the load and performance requirements call for high power, two or more engines may be needed. With two engines, either tandem or twin tractor installation may be employed. The advantages of the tandem arrangements are :—

(*a*) Less head resistance.
(*b*) The power is applied along the centre line of the aeroplane, so if one engine cuts out, the rudder need not be applied.
(*c*) Shorter lengths of fuel lines therefore less trouble with connections and leakage.
(*d*) Shorter lengths and simpler arrangement of engine and controls.
(*e*) The installation is easier for inspection purposes.
(*f*) The engines are easier to support.

The disadvantages are as follows :—

(*a*) Less flexibility of control in the air as a result of the centre-line position of the engines.
(*b*) With the forward engine cut out, the airscrew of the rear engine operates at low efficiency, as it is designed to work in the slip-stream of the forward airscrew.
(*c*) With air-cooled engines the cooling of the rear engine is very inefficient.

The quadruple and sometimes the triple tractor arrangement is favoured in general utility aeroplanes, owing to the safety factor afforded if one engine cuts out it does not necessarily terminate the flight as it usually does when the total power is divided between two engines only.

Reduction Gears

A geared drive in the engine is to obtain increased airscrew efficiency as well as increased thrust at take off. Airscrew revolutions should be approximately 10 r.p.m. per mile per hour ; thus, in an aeroplane doing 120 m.p.h. the airscrew speed should not exceed 1,200 r.p.m. If high power is obtained by high crankshaft speeds a " reduction gear " must be incorporated in the engine design for airscrew efficiency. With geared engines the following improved performances may be expected :—

(*a*) Shorter run to take off.
(*b*) Greater take-off load.
(*c*) Greater range.
(*d*) Increased climbing speed.
(*e*) Higher top speed.

With the advantages of reduction gears certain disadvantages arise.

The weight is increased.

The reduction gear mechanism and the stresses involved complicate the engine design.

Reduction gearing is always a potential source of mechanical trouble and this, coupled with its additional cost, is against its use.

ESSENTIAL REQUIREMENTS OF MODERN AEROPLANES

SECTION II—BIPLANE v. MONOPLANE—STRUCTURAL CONSIDERATIONS

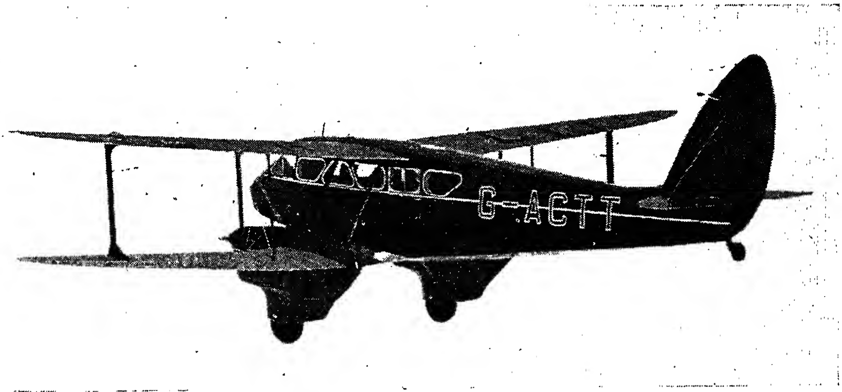


Fig. 1.—TWIN-ENGINED PASSENGER OR FREIGHT-CARRYING BIPLANE. "*Flight.*"
The D.H. "Dragon." An eight-seater. Maximum speed 130 m.p.h. Note that two-bay wing bracing is employed.

IN Section 1 of this article, we considered the essential requirements of aeroplanes for different purposes and the design of the power plant. We will now consider the relative advantages of biplane and monoplane construction, and other factors affecting design.

BIPLANE v. MONOPLANE

Aerodynamic Advantages of Biplane Construction

(*a*) Slightly better control and manœuvrability are obtained.
(*b*) The position of the centre of pressure may be adjusted by altering the arrangement of the planes to alter the stability.
(*c*) There is less tendency to wing flutter.
(*d*) The designer can vary the gap-chord ratio and the stagger to improve the longitudinal stability.
(*e*) The ailerons are closer to the fuselage which gives lighter aileron control and improves the manœuvrability.

Aerodynamic Disadvantages of Biplane Construction

(*a*) Interference of the air flow between the planes is bound to occur.
(*b*) Double the number of plane tips result in loss of lift and increased drag.

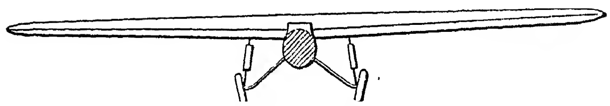


Fig. 2.—IN THE MONOPLANE STRESSES ON THE WINGS ARE TAKEN INTERNALLY.

Methods of construction vary. Two typical examples are given in Figs. 3 and 4.

(c) Increased head resistance due to struts, wires and external fittings.

As a result of the above, given equal aspect ratios, a biplane will have a smaller lift coefficient and a smaller lift-drag ratio at all angles of attack.

Aspect Ratio of an Aerofoil

The ratio of the span to the mean chord of a wing is fairly well established. The number of aerofoils and their areas must now be determined. Improved vision and structural arrangements will probably have to be made as the design progresses, involving minor alterations in the size and position of the aerofoils.

Cantilever Wings

Fig. 2 may be of single-, two- or multi-spar construction, the stresses are taken internally. The method of construction varies and will be dealt with under the various types of aeroplanes.

Wing Bracing

The method of bracing employed depends mainly on the aspect ratio and the aerofoil section chosen. It may be internally braced if the aspect ratio is low or if a thick aerofoil section is selected. As the aspect ratio increases external bracing is most economical.

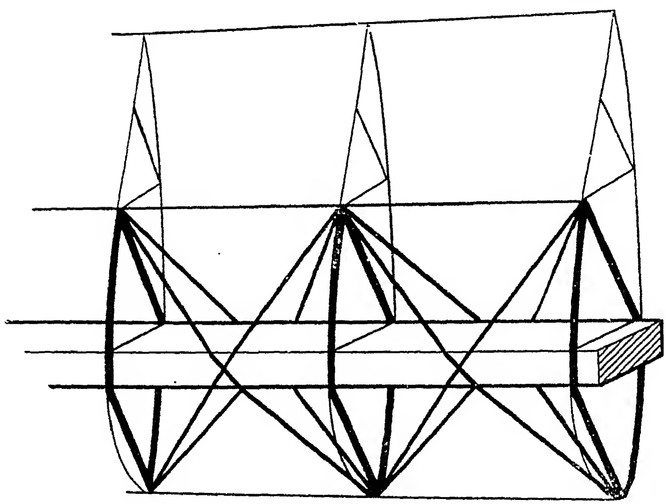


Fig. 3.—A TYPICAL SINGLE SPAR CONSTRUCTION FOR THE CANTILEVER WINGS OF MONOPLANES.

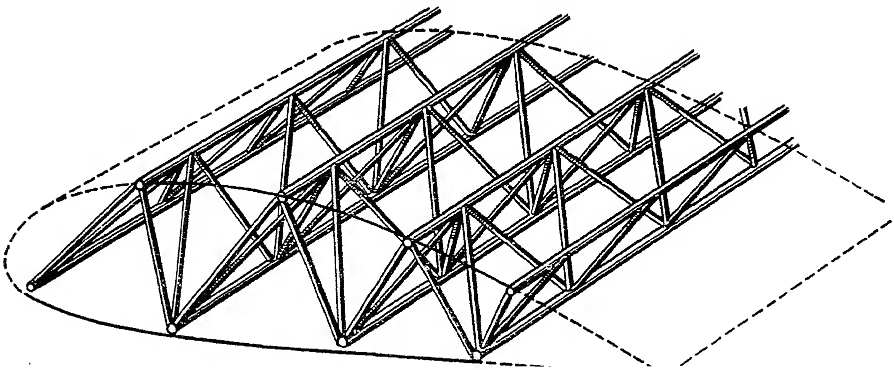


Fig. 4.—TYPICAL MULTI-SPAR CONSTRUCTION FOR THE CANTILEVER WINGS OF MONOPLANES.

Single Bay Bracings

Fig. 5 shows a common method of single bay bracing.

In Fig. 6 the outer strut is employed to prevent torsion and vibration of the wings.

Two-Bay Bracing

If the span is further increased the employment of a two-bay bracing as shown in Figs. 7, 8, and 9 is necessary. That shown in Fig. 7 is the most common. Unequal bays are sometimes employed, the outer being from 30 to 40 per cent. longer than the inner.

In Fig. 8 the stress may change direction in all members, so that steel tubing supplants wires, wooden struts being unsuitable to take the tension required. It is usual to alter the bracing as shown by the dotted lines in order that the members in compression for normal flight may be as short as possible. This type is heavier than that in Fig. 7.

Fig. 9 may be considered as a two-bay structure or as a single-bay bracing, in which the lower spar is a bracing beam with a strut at the centre. An advantage of this type is that the wires at all times are in tension, and the spars always in compression. This type is impracticable in spans of over 30 ft., as the bracing becomes too flat, owing to the small gap.

Triplane Bracing

Triplane bracings are of two main types. These are shown in Figs. 10 and 11. In Fig. 10 the analysis is the same as that for the bracing shown in Fig. 9.

The second, Fig. 11, is a double bracing similar to that in Fig. 7. Here the wires may be attached to the centre aerofoil, or may be passed through holes in it.

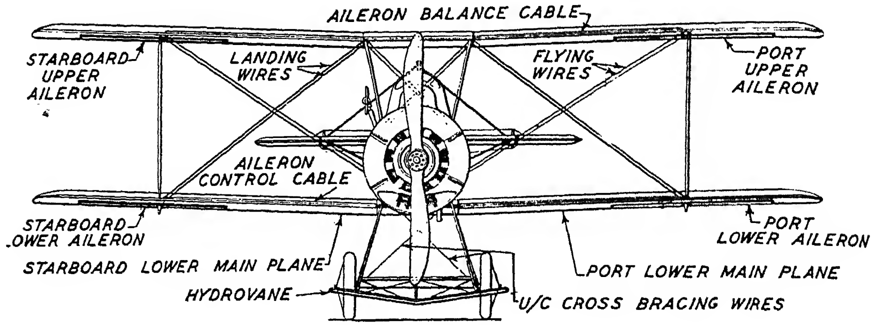


Fig. 5.—SINGLE BAY BRACING—A VERY COMMON METHOD.

Wing Loading

The area of the wings and the weight of the aeroplane having been determined, a check is possible on the wing loading which is the result of the former divided by the latter. The amount of the wing loading and the magnitude of the maximum lift coefficient of the aerofoil in turn determines the minimum speed of the aeroplane in steady horizontal flight. The wing loading varies for the different types of aeroplane as shown in the following table :—

Type of Aeroplane.	Wing Loading—lbs./sq. ft.
Fighter	$7\frac{1}{2}$ — 12
Reconnaissance	9 — 12
Training	7 — 9
Torpedo	11 — 13
General purpose	13 — 16

Fuselage Dimensions

The minimum fuselage depth for a normal aeroplane is 42 in. if the pilot is to be protected from the air pressure. In military aeroplanes where the gunner may have to stand to operate his guns, at least 5 ft. is required if he is to be protected from the air pressure. An advantage of a deep fuselage is that it may be constructed somewhat lighter than a shallow one and still have equal or greater strength where most needed.

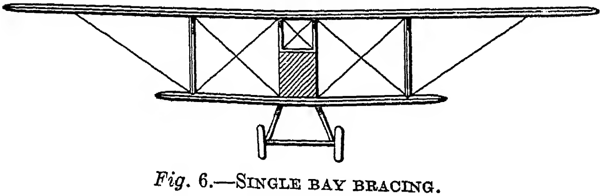


Fig. 6.—SINGLE BAY BRACING.

In this case an outer strut is employed to prevent torsion and vibration of the wings.

The vertical loads are much greater than the horizontal, so that greater strength is needed in the vertical plane where the deep bracing gives increased strength.

Minimum Sizes

The minimum limit on fuselage width is 26 in. If narrower than this the pilot has insufficient room to use the controls and he will suffer discomfort due to being cramped. Width in excess of the minimum is a disadvantage as visibility is impaired and head resistance increased.

STRUCTURAL CONSIDERATIONS

Wood versus Metal

One of the first considerations to be settled by the designer is whether to use metal or wood for the aeroplane construction. The advantages and disadvantages are as follows :—

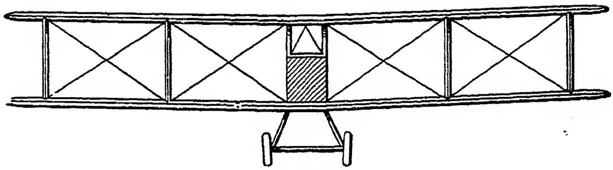


Fig. 7.—TWO-BAY BRACING.

The above method is the most common for two-bay bracing. Unequal bays are sometimes employed.

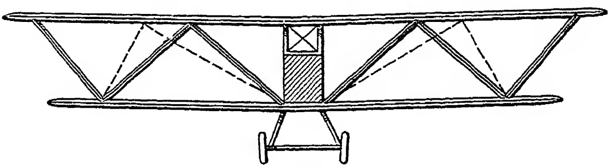


Fig. 8.—TWO-BAY BRACING.

Steel tube struts are used in this case because the members may come under compression and tension. This type is heavier than in Fig. 7.

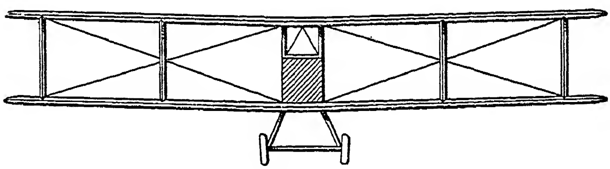


Fig. 9.—A TWO-BAY STRUCTURE WHICH MAY ALSO BE CONSIDERED AS A SINGLE BAY BRACING.

This type is impracticable in spans over 30 ft.

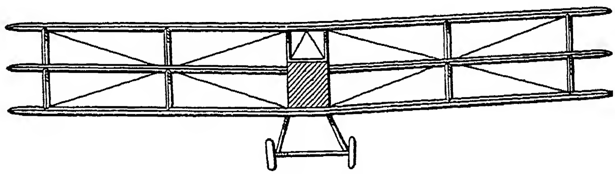


Fig. 10.—TRIPLANE BRACING.

The bracing is similar to that shown in Fig. 9.

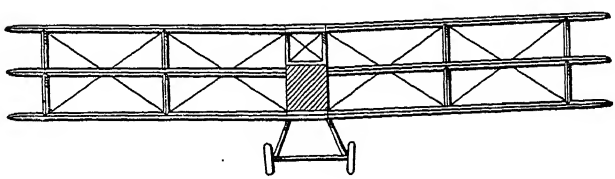


Fig. 11.—ANOTHER TYPE OF TRIPLANE BRACING.

This has double bracing similar to that in Fig. 7.

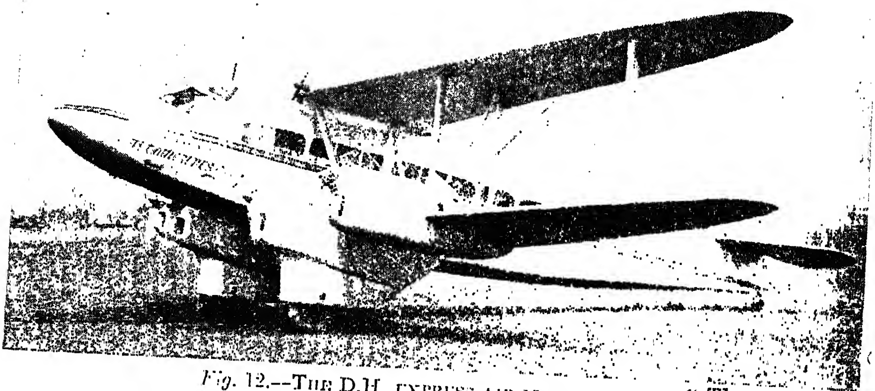


Fig. 12.—THE D.H. EXPRESS AIR LINER. "*The Aeroplane.*"

Accommodation for two pilots (dual controls) and up to fourteen passengers. Note the two bay wing bracing.

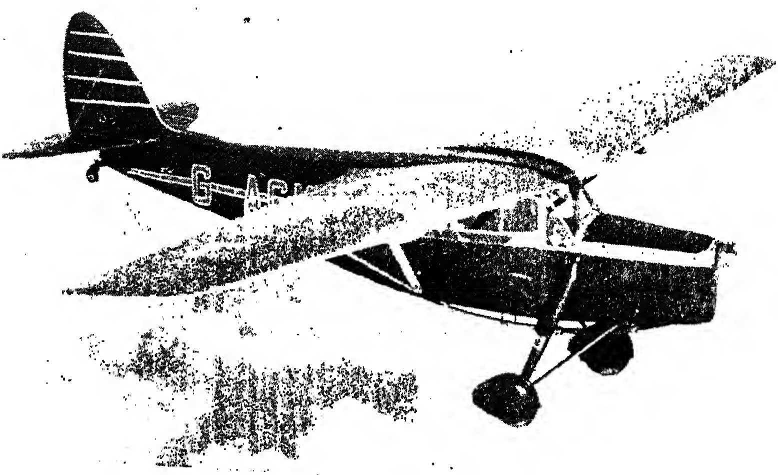


Fig. 13.—THE D.H. 85 "LEOPARD MOTH." (130 H.P. "GIPSY MAJOR" ENGINE). "*Flight.*"

Advantages of Metal

(*a*) Costs compare favourably, and suitable timber is scarce.
(*b*) Makes a neater job.
(*c*) Metal yields and bends, has greater local strength and in a crash less danger to the occupant from splinters.
(*d*) Less material wasted.
(*e*) Greater strength for minimum weight. Wood does not possess well-defined properties; it varies with density, degree of humidity and source. Wood is not homogeneous.
(*f*) Less possibility of fire.
(*g*) Greater rigidity.
(*h*) No distortion or increase in weight due to moisture.

Disadvantages of Metal

(*a*) More difficult to repair if away from a workshop.
(*b*) In some cases there is no early evidence of internal deterioration.
(*c*) Difficulty in the manufacture of a new type owing to expensive jigs.
(*d*) If welded, strength of weld cannot be guaranteed.
(*e*) Engine bearers difficult to replace except as entire mounting.

In view of the numerous and important advantages of metal over wood construction, it is gradually supplanting the latter.

The Question of Floats

Metal floats have the following important advantages over wooden floats :—

(*a*) The average life of a wooden float operating under normal conditions is approximately one year; metal floats have a much longer life.
(*b*) Metal floats compared on a basis of weight per pound displacement are from 7 to 10 per cent. lighter than wooden floats.
(*c*) After a short time in use soakage may represent up to 10 per cent. of the weight of a wooden float. This is non-existent in a metal float.
(*d*) Metal floats are less susceptible to deterioration through exposure if treated correctly against corrosion.
(*e*) Damage as a result of a collision will probably be more localised in a metal float.

A disadvantage is that metal floats are more costly when compared on a basis of cost per pound displacement.

The advantages and disadvantages of various materials must be studied to determine the most acceptable for each part of the structure.

Little or no weight is saved with metal if exact duplication of design as visualised in wood is followed. With metal construction a weight saving of about 25 per cent. may reasonably be expected for the same strength as for wood.

Structural Aspects of Size

The size of an aeroplane is not only limited by the weight, but also its control in the air and the limit imposed by aerodromes. The employment of servo-motors to actuate the controls together with brakes to shorten the run after landing have all raised the feasible limit of size. Weight may be reduced by using materials to the best advantage. The rectangular spar section of early aeroplanes has been superseded by I beam sections, which in turn have been supplanted by box girder sections in larger sizes and in very large aeroplanes by latticed sections or structures utilising the external skin for strength with a minimum of internal bracing.

Simplicity of Structure

The simpler the structure of the aeroplane, the greater will be the accuracy with which the designer can calculate the stresses in the various members and what materials it is best to employ.

Where the structure is such that the stresses offer a wide range of possible values, it is essential to make the members strong enough to support the highest stresses which can be calculated. Excess weight will then be incorporated which will reduce the performance of the completed aeroplane. The more complicated the layout, the greater will be the chances of error in calculating the stresses. Simplicity of structure is therefore desirable.

Less time will be required for manufacture and costs will be lower. Assembly and alignment will be easier. Complicated fittings have more points of possible weakness than simple ones. Manufacture is easier with simple designs. This involves the following :—

- (*a*) Designing so that material will not be unduly wasted.
- (*b*) Avoiding the design of parts which are clumsy to handle and manufacture.
- (*c*) Designing the tools, jigs and fixtures which will simplify manufacture.
- (*d*) Making as many parts as possible interchangeable.
- (*e*) Deciding as to whether parts shall be manufactured in the shop or sub-contracted for standard engineering parts.

Accessibility of the Structure

In order to give satisfactory service, the designer must consider the accessibility of the structure for periodic inspection, necessary repair

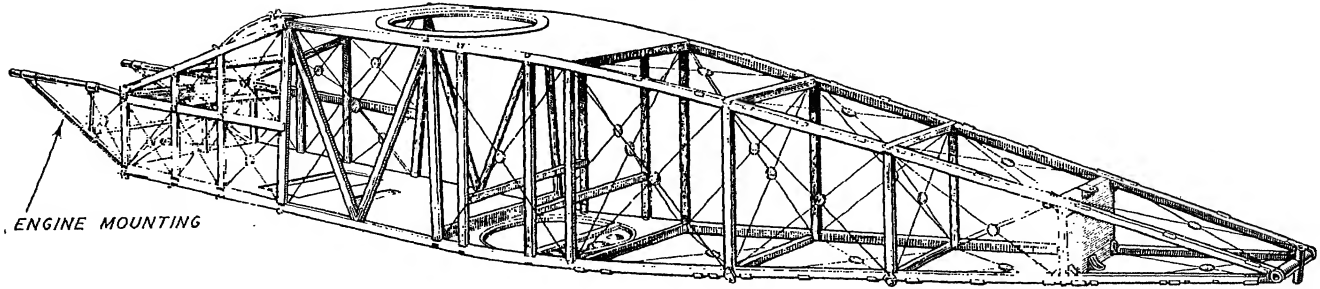


Fig. 14.—WOODEN TYPE FUSELAGE.

Showing the "stick and wire" type made up of four longerons held together with vertical and horizontal struts of wood and diagonal bracing wires in the three dimensions.

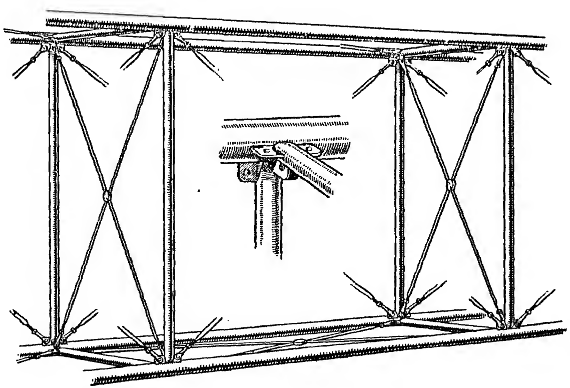


Fig. 15.—METAL TYPE FUSELAGE.

Showing welded connections for longerons, struts and wires.

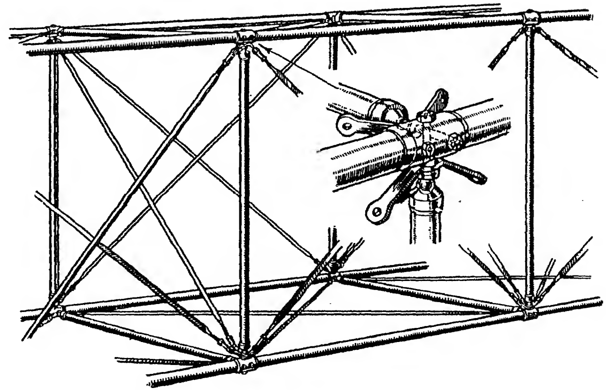


Fig. 16.—METAL TYPE FUSELAGE.

This has fitted connections for longerons struts and wires.

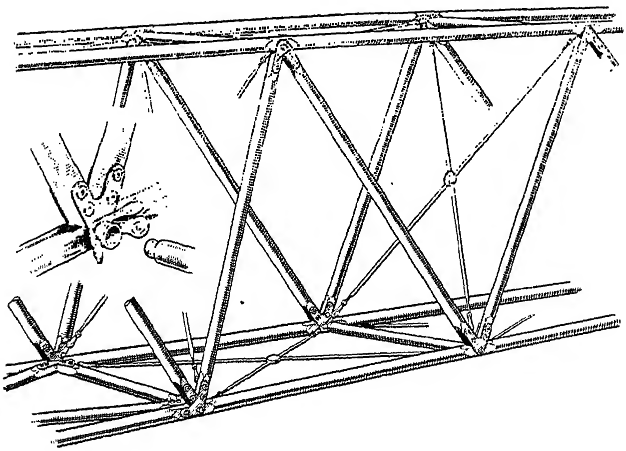


Fig. 17.—METAL TYPE FUSELAGE CONSTRUCTION.

In this case the wires are replaced by struts taking both tension and compression.

and for easy and rapid installation and removal of the power plant, equipment and such parts as require frequent replacement.

Periodic and careful inspection is of vital importance. Immediately deterioration sets in it must be discovered. All fittings must, as far as practical, be accessible. Inspection plates, cowling, etc., should be of adequate size not only to make inspection easy, but also to permit of quick repair.

Removal of wood or metal skin subsequent to inspection and its replacement is almost as expensive as installing a new assembly and much more laborious.

With fabric covering to wings and fuselage this is not the case. Removal, inspection, repair and recovering consume but a short time and a fraction of the expense.

In all aeroplanes the power plant and other equipment must be easily and quickly inspected and repaired if they are to operate efficiently. Speed is the essence of aeroplane activities, so that delays must be reduced to a minimum. The demand, however, for compactness often seriously affects accessibility.

Structural Considerations

Within the limits imposed by aerodynamic effectiveness and operating function, the designer must consider :—

(*a*) Maximum vision.
(*b*) Comfort of the crew.
(*c*) Ease of leaving the cockpit with parachutes.
(*d*) Safety of the personnel in minor crashes.

The requirement of adequate vision is of the utmost importance with aeroplanes. The pilot must have a field of view which will permit him to fly his aeroplane correctly as well as to take off and land with safety.

With load-carrying aeroplanes this involves very exacting distribution of the structure.

The blind area must be so minimised as to preclude the possibility of any other aeroplane approaching unseen.

Comfort of the crew must be considered, as this ensures better handling of the controls and equipment over longer periods.

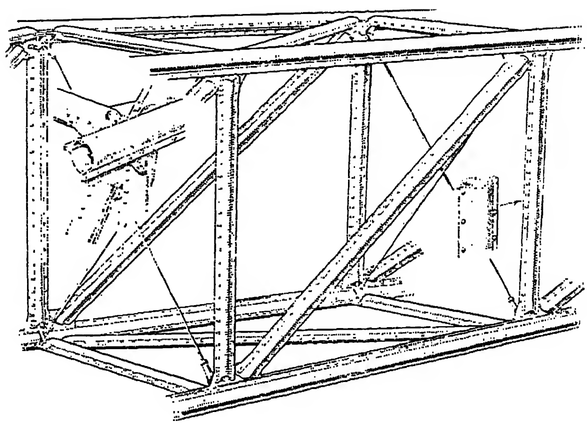


Fig. 18.—ANOTHER METAL TYPE FUSELAGE WITH TAKING BOTH TENSION AND COMPRESSION.

In case of emergency, all members of the crew should be able to take to their parachutes with promptness and ease. This requirement entails a careful distribution of cockpits, struts, wires, etc.

Injury in minor crashes may be largely obviated by well-distributed padding on sharp edges, avoidance of projections and the incorporation of a safety belt.

Typical means of accomplishing these are outlined below.

Fuselage

(*a*) Frontal area of the engine of a single-tractor engine installation should be as small as possible to permit maximum vision ahead.

(*b*) Cockpit openings should have ample room for the pilot to move head and shoulders and so permit him to look around and over the sides of the fuselage. Similar facilities are to a slightly lesser extent necessary for the crew.

(*c*) The fuselage width should be of the minimum feasible for operation and comfort, since a wide fuselage cuts down the view ahead and alongside.

(*d*) Side windows are of value in deep fuselages to secure vision forward and downward.

Fuselage Types and Characteristics

The fuselage is to provide accommodation for the crew, useful load, equipment and in most cases, the power plant. It serves as a means of connection in large aeroplanes between the other component parts of the structure. It carries the tail and provides keel surface for directional stability. In itself it is a vital component where failure of any member

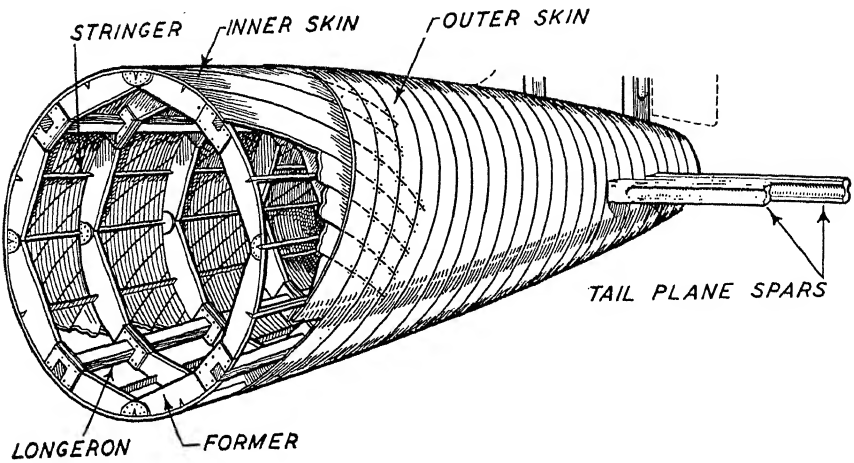


Fig. 19.—WOODEN MONOCOQUE FUSELAGE CONSTRUCTION.

This type is usually made from three to five ply wood strip, wrapped in spirals around a form glued in place and reinforced at intervals by bulkheads.

will be dangerous. The utmost care must be exercised in determining the stress in every individual member.

Fuselages may be divided into the following general types :—

(*a*) " Stick and wire " type, made up of four longerons, together with vertical and horizontal struts of wood and diagonal bracing wires in the three dimensions.

(*b*) Metal type, with welded or fitted connections for longerons, struts and wires.

(*c*) Metal type, with longerons and struts, wires being replaced by struts taking both tension and compression.

(*d*) Monocoque type, ordinarily made of from three to five ply wood strip, wrapped in spirals around a form glued in place and reinforced at intervals by bulkheads. In some cases longerons are incorporated as well as heavier bulkheads at smaller intervals, and a thinner skin is employed. This type is, in some cases, made of metal.

(*e*) Another form of construction is known as geodetic. This consists of curved geodetic members spiralling round the main longitudinal frame members.

Characteristics of Wing Bracing

Before making an analysis of the wing bracing, the characteristics desirable should be considered.

These are as follows :—

(*a*) Lightness.
(*b*) Rigidity.
(*c*) Low resistance.
(*d*) Durability.
(*e*) Low cost.
(*f*) Ease of construction.
(*g*) Ease of maintenance.
(*h*) Freedom from interference with vision.

Wing members fall into two principal classes—stressed members, and non-stressed members. In the first are :—

(*a*) Spars.
(*b*) Ribs.
(*c*) Interplane struts.
(*d*) Lift and anti-lift wires.
(*e*) Drag and anti-drag wires.
(*f*) Compression ribs.
(*g*) Fabric (or other stressed wing covering).

In the second are :—

(*a*) Leading and trailing edges.
(*b*) Former ribs.
(*c*) Formers.
(*d*) Streamlining.
(*e*) Fairing pieces.

The second group is designed to preserve the shape of the parts.

Loads on Wing Bracing

The loads affecting the wing bracing are determined by three methods :—

(*a*) Mathematical.

(*b*) A combination of wind-tunnel results and mathematical calculations.

(*c*) Test flights.

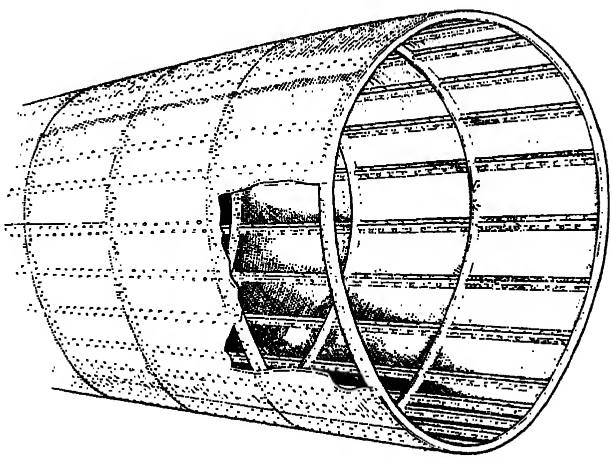


Fig. 20.—METAL MONOCOQUE FUSELAGE CONSTRUCTION.

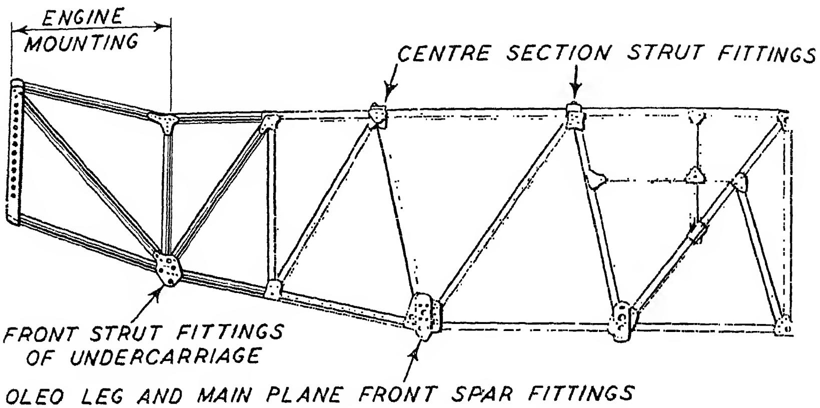


Fig. 21.—FRONT END OF METAL TYPE FUSELAGE.

Characteristics of the Landing Gear

Lift is obtained from the aerofoils. All other parts produce resistance. The landing gear constitutes a total loss, which is minimised by reducing weight and streamlining as much as possible or making it retractable.

The landing gear may be of wheel or float type. The former consists of the undercarriage and the tail skid and the latter includes the main floats and auxiliary floats.

While it is impossible to design a landing gear which cannot be crashed, it is the aim of the designer to make it strong enough to withstand the shocks of reasonable landings and provide for the absorption of energy.

Structural Analysis

The engineer, having approved of the preliminary design, is ready to estimate the highest probable loads acting on the structures and the consequent stresses in the individual members. He cannot attempt to analyse any and all conditions to which an aeroplane might be subjected. Certain conventional procedures have been adopted for standard conditions of loading, which have been found by experiment to be adequate in providing structures capable of safely and efficiently performing the duties demanded. This procedure has been adopted for the following component groups of an aeroplane :—

(*a*) Wing bracings.
(*b*) Wings.
(*c*) Fuselage.
(*d*) Landing gear.
(*e*) Control surfaces.

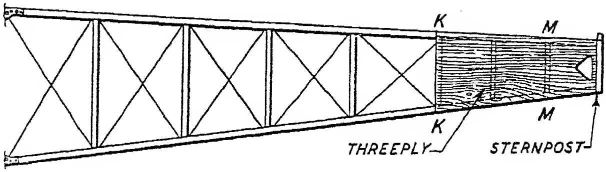


Fig. 22.—STERN END OF WOODEN TYPE FUSELAGE.

These groups are considered for conditions enumerated below :—

(*a*) High angle of attack.
(*b*) Low angle of attack.
(*c*) Inverted flight.
(*d*) Three-point landing.
(*e*) Dive.

The designer is then faced with the following questions :—

(*a*) What manœuvres or loading condition will produce the greatest stress ?
(*b*) What is the magnitude of that maximum stress ?

He should then carry the analysis of each group to a point which will indicate for all individual members the critical loads for the conditions outlined above. The final results of critical loads for all members of the structure is not a statement of stresses found to exist simultaneously, but a list of the worst stresses for the conditions investigated.

On the basis of these figures the engineer then proceeds to select the materials and sizes for the individual members.

The principles of structural analysis are the same in all engineering work. The aeroplane designer, however, must employ these principles with the utmost accuracy if the aeroplane is to be a success. He must obtain the necessary strength for a minimum weight and he must not allow any errors to creep into his calculations.

Factor of Safety

In engineering practice, structures are designed for stresses much less than the ultimate strength and well below the elastic limit of the material. Under the worst conditions likely to occur, the material is stressed to a fraction of the amount at which it would fail. The ratio of breaking strength to the worst working stress is termed the " factor of safety." The factor of safety for aeroplanes is expressed as the ratio of the design load to the maximum load.

Aeroplanes are designed with a very small factor of safety as compared with other structures. With most structures values of from 4 to 10 are common, but in aeroplanes every effort is made to ensure a value of not more than 2.

The load for which a member is designed is called the " design load."

The " basic loads " on an aeroplane are the loads on the aeroplane when it is at rest.

The "load factor" is the ratio of the failing load of a member or structure to the assumed basic load under a specified flight condition. This must not be confused with the term "factor."

The "ultimate load" is the load that causes failure of a member.

External Loads

All stresses in an aeroplane are caused by loads which are external and must at any moment satisfy the conditions of equilibrium. The structure must transmit any load from its point of application to a point where it will be balanced by some other external load.

Internal stresses are set up in the load-carrying members.

The next step in structural analysis is the determination of the loads on the various parts of the aeroplane assembly when considered under normal loading conditions. In general these loads or forces are :—

(*a*) Air pressures.
(*b*) Weight.
(*c*) Inertia forces.
(*d*) Ground reactions.
(*e*) Engine torque.
(*f*) Airscrew thrust.
(*g*) Reactions between assemblies.

The *air pressures* are the lift and drag.

The *weight* is produced by gravity acting on each part of the structure in proportion to its mass.

The *inertia forces* are those produced by the acceleration imparted to the aeroplane in any movement which causes it to depart from a condition of equilibrium either at rest or in uniform motion. The inertia forces are equal and opposite to the forces producing the acceleration.

The *ground reactions* are the neutralising forces met at the instant when the aeroplane has a certain vertical downward component which is rapidly reduced to zero by the action of the ground.

The *engine torque* is a couple which usually acts as a down load on one engine bearer and as an up load on the other. This is due to the fact that the engine tends to rotate in an opposite direction to the rotation of the airscrew. Action and reaction are equal and opposite.

The *airscrew thrust* is the force exerted by the airscrew on the fuselage in pulling it through the air against the drag.

The *reactions between assemblies* are such forces as those exerted by the aerofoils on the fuselage. Here the lift and drag forces resulting from the action of the air on the aerofoils are transmitted to the fuselage.

MATERIALS FOR AIRCRAFT CONSTRUCTION

By Squadron-Leader H. Nelson, M.B.E., M.I.B.E., A.M.I.Mar.E.

THE following must be considered when determining the relative merits of materials :—

(*a*) Availability.
(*b*) Cost.
(*c*) Adaptability to construction.
(*d*) Strength-weight ratio.
(*e*) Resistance to corrosion or decay.
(*f*) Resistance to wear, shock and fatigue.
(*g*) Modulus of elasticity.

In aeroplane construction the above points are of great importance in the selection of the best material for the purpose under consideration. As soon as new materials become available and their superiority proved, a use is found for them in aeroplane construction.

Availability and Cost

Availability and cost are related by the law of supply and demand. Cost increases when demand is greater than supply. Spruce, which was used in the past for aeroplanes, is to-day in this category. On the other hand where the supply is greater, the material will be relatively cheaper. Sitka spruce is, however, being grown in large quantities in England under the afforestation scheme.

With military aeroplanes the cost is of secondary consideration in relation to several other factors.

By laboratory methods small quantities of very high, strong metallic alloys have been produced. Such materials might be ideal for aeroplane construction, but owing to the limited supply their use is not practical.

To be used from a standpoint of availability and cost, the material must be such that it can be produced in large quantities and at a competitive price.

Adaptability to Construction

Adaptability to construction involves the following points :—

(*a*) Accuracy in manufacture.
(*b*) Ease of working.
(*c*) Ease of assembly.
(*d*) Wastage.
(*e*) Ease of repair.
(*f*) Possibility of fire.

Fig. 1.—MAHOGANY BOARDS USED FOR AIRSCREW CONSTRUCTION IN THE CONDITIONING KILNS.

Special attention is paid to seasoning the selected mahogany boards, which are passed through conditioning kilns to ensure the amount of moisture being kept within limits of 12–14 per cent. This condition is maintained throughout the various stages of manufacture.

Some materials lend themselves to accurate manufacture more readily than others.

Accuracy of manufacture is more easily attained with metal than with wood, owing to the greater homogeneity of the material.

Ease of working includes various operations, such as bending, forging, machining, spinning, etc. Where such operations are difficult skilled mechanics must be employed, with a consequent increase in the cost of the manufactured part.

Ease of assembly involves the operation of joining manufactured parts by riveting, welding, brazing, soldering, etc. It also includes the ease with which jigs may be used. The probability of damage resulting from the joining process as in welding must be considered. Tubular fuselages of carbon and chrome molybdenum steel may be assembled by welding. The process employed in assembly depends upon the characteristics of the material, the strength afforded and the ease with which the joint is made.

Wastage of material is of importance. The more homogeneous the material, the less likely will be the discovery of flaws which is the cause of

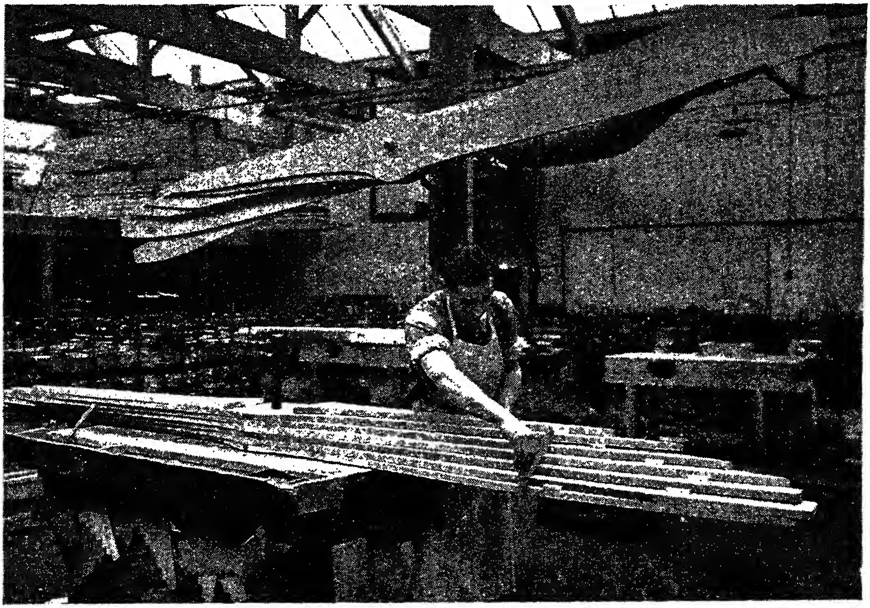


Fig. 2.—ASSEMBLING THE LAMINÆ FOR CONSTRUCTING AN AIRSCREW.

The laminæ are first loosely assembled on the balance seen in the upper part of the picture. Accurate positioning is then determined by a stepping gauge (which is shown being applied to the assembly of laminæ on the bench) and small blocks of wood are fixed temporarily to the laminæ to locate their position.

wastage. It has been estimated that less than one-third of the wood purchased for aeroplane construction goes into the finished article; whereas with metal about two-thirds of the material finds its way into the finished structure.

If materials are employed in the structure of an aeroplane with which mechanics are not conversant, difficulties are experienced in making repairs. In consequence of this difficulty materials should be used in construction which will permit rapid and reliable repairs to be made. Certain advantages accrue from the employment of materials with desirable characteristics other than ease of repair. While repair to a wooden hull is readily accomplished, the wood in service soaks up water, with a consequent increase in weight.

This drawback is avoided in metal hulls, but the repair is more difficult. Repairs to a metal hull are not as frequent as in the case of a wooden one, owing to the greater local strength of the material. Corrosion is, however, a serious factor.

In the selection and employment of materials the possibility of fire should never be overlooked. While the likelihood of fire in the air has

been minimised it will never be eliminated. Other things being equal, materials should be selected which are the least inflammable.

Strength-Weight Ratio

When considering the merits of various materials for construction of an aeroplane, the most important factor is the strength-weight ratio. Since the structure, exclusive of the engine, tanks, etc., represents about 30 per cent. of the total weight of the aeroplane, it is clear that the designer must keep the weight of each part to a minimum.

Every pound that goes into the structure means one pound less of useful load that can be carried if the required performance is to be met.

The advantage of one material as compared with another may be regarded as increasing with the square of the strength-weight ratio.

The accompanying table gives the strength-weight ratio of some of the aeroplane materials.

Steel of suitable section for working might be considered over-strength, and consequently over-weight, whereas duralumin meets the requirements of strength and weight more satisfactorily. Wood compares well with duralumin in this respect, but due to its non-uniformity, lack of ductility, water absorption, etc., it is not as favourable, particularly as there is difficulty in the supply of suitable spruce and ash.

STRENGTH-WEIGHT RATIO

	Yield Point Tons per sq. in.	Ultimate Stress Tons per sq. in.	Specific Gravity.	Ultimate Stress Specific Gravity.	Relative Strength Weight Efficiency.	Comparative Weight for same strength.
High tensile alloy steel. . . .	55	65	7·9	8·2	0·91	1·1
Alloy steel . .	45	55	7·9	7·0	0·78	1·3
Duralumin . .	15	25	2·8	9·0	1·0	1·0
Spruce		End grain Compression 5,000 lb. per sq. in.	0·38			
Aluminium sheet.		9	2·7	3·3	0·37	2·7
Mild steel . . .	12	25	7·9	3·2	0·36	2·8

Resistance to Wear, Shock and Fatigue

A maximum resistance to wear, shock and fatigue must be possessed

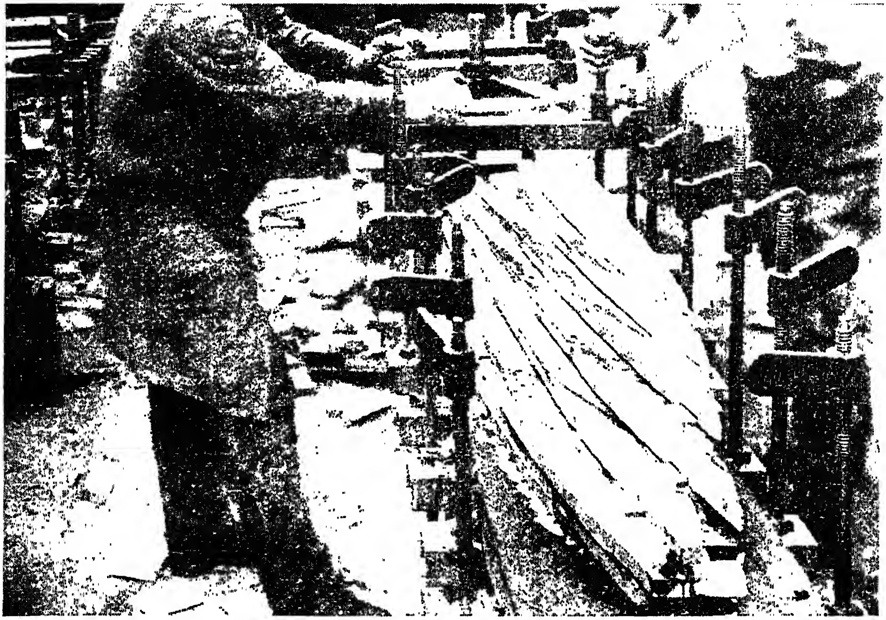


Fig. 3.—THE NEXT STEP IN WOOD AIRSCREW CONSTRUCTION.

The laminæ, having been correctly assembled and located as shown in Fig. 2, are taken apart and placed one by one on the glue table, casein glue being applied, until all the laminæ are in position as located by the small blocks previously applied. Cramps are then fitted about 10 in. apart, working outwards from the centre, as shown, and the block remains cramped for 24 hours.

by materials in order to obtain a satisfactory life for an aeroplane. Wear due to vibration, shock, bad landings, fatigue and stress reversals, all tend to reduce the life of the structure. Without being over-strength, each part of the aeroplane should be designed for the material best suited for the particular purpose. Streamline wires, as early manufactured, quickly crystallised from vibration in flight, with resulting fracture. Cold drawing has obviated this fault. Fatigue has less effect on wood than on metal and is more easily discovered.

Resistance to Corrosion, Decay, etc.

It is desirable that the material of which an aeroplane is constructed should be unaffected by changes in climatic conditions, or by unfavourable storage. None of the materials now in use can fulfil these requirements, although steel and duralumin are not subject to much change in different climatic conditions. Both materials are susceptible to the action of moisture if unprotected, particularly in inaccessible interiors, where failure is normally the first evidence of deterioration.

In the case of wood it is not possible, even by careful varnishing, to

protect it from the action of moisture. Wood stored in a damp place may swell or crack, and become unserviceable. A wing constructed of wood and sent to a locality of low humidity might, under certain circumstances, dry to a 5 per cent. moisture content with consequent shrinkage, causing the wood to draw away from the fittings and loosen up the entire structure. The wood may split around the bolt holes, and render the structure unsafe for air work. Long storage under dry conditions is particularly bad for hulls, floats and plywood fuselages—a common fault being warping and splitting.

Fabric-covered fuselages and wings must always be reconditioned after long storage, as the fabric becomes useless. Wooden airscrews, if stowed where temperature and humidity control are not available, will develop spongy tips, laminations will warp and they will become unbalanced. This deterioration of wooden airscrews in storage, together with their being damaged by rain, hail, etc., has been a strong argument for the development of metal blades.

GENERAL NOTES ON AEROPLANE WOODS

Species Used

One of the most common materials used for structural purposes is wood, which has many advantages over other materials.

There are a variety of factors entering into a consideration of its use; only by a careful study can one make a selection of the kind of wood suitable for any specific purpose.

In aeroplane construction any wood used must combine at the same time the characteristics of lightness, strength and stiffness. Practically all woods have, at some time or other, been employed, but the following are most commonly used—spruce, ash, mahogany and walnut.

Uses of Different Species

Spruce.—This is used in the manufacture of struts, spars, longerons and in hull and float construction.

Ash.—This is used in the manufacture of longerons, chines, tail skids and struts.

Mahogany.—This is used for veneer parts and airscrews, bottom and bulkhead planking of floats and hulls. Cedar is almost as good.

Walnut.—This is used in the manufacture of airscrews, but mahogany is more usual.

Factors Affecting Strength

Compared with other materials, certain woods have, for their weight, remarkable strength. Spruce in tension is 2·5 times as strong as steel for the same weight and length and in compression it is twice as strong. The strength of wood, however, is affected by many factors, included among which are: kind, structure, age and time of the year when felled,

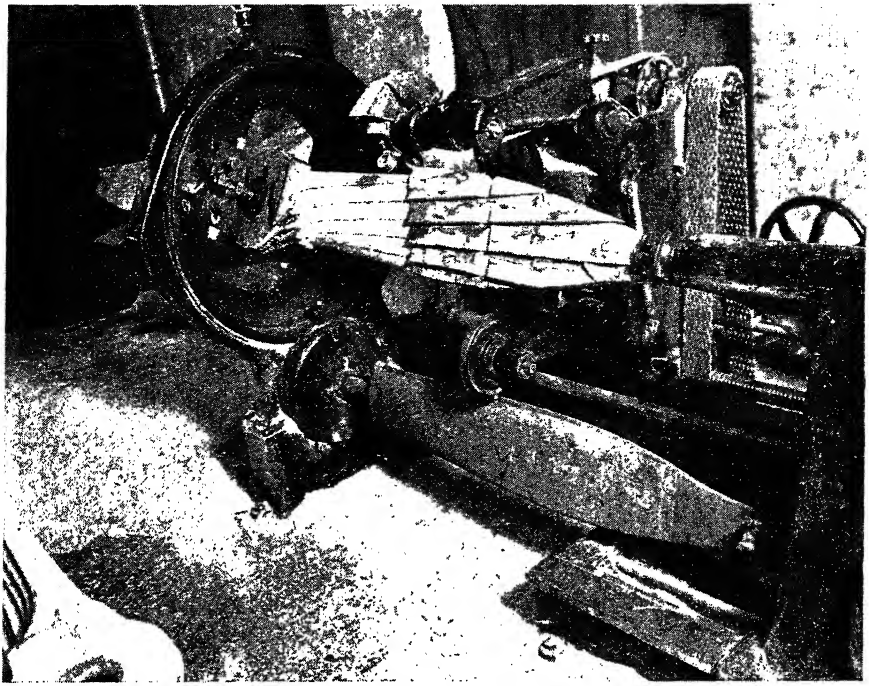


Fig. 4.—ROUGH SHAPING THE AIRSCREW.

Here we see the rough shaping being done on an automatic profiling machine. Note the metal former, which serves as a guide to the shape of the airscrew, being traversed by a tracer wheel.

moisture content, seasoning, defects, amount of sapwood and heartwood, method of sawing, etc. It will be seen that these may make wood an expensive material for aeroplane construction.

Structure of Wood

Examination of a sawn log shows a small pith at the centre, surrounded by numerous concentric rings, which are in turn covered by the bark. The concentric rings are the layers of wood added each year during the life of the tree. These rings indicate the age of the tree. The thickness of the annual rings varies greatly in different trees of the same species, and in different parts of the same cross-section. Trees grown in the open have wider rings than those grown more slowly in a forest.

Normally the rings are widest at the centre, and become narrower nearer the bark. Also the width of the same ring will vary from the bottom to the top of the tree.

With the conifers, such as spruce, a medium rate of growth produces high strength and toughness ; whereas a rapid growth is best to produce maximum toughness and strength in hardwoods like hickory.

Examination of a single annual ring shows that it is not uniform in composition. In spruce the interior of the ring, that is, the early wood, is lighter in colour than the outer; the opposite is true in the case of the oak. In forest grown trees the growth is upwards more than outwards and the reverse if grown in the open.

The early wood is called the spring wood, and the later wood the autumn wood. Since the autumn wood is denser, harder and stronger than the spring wood, it follows that the percentage of the former gives information concerning its mechanical properties.

Grain of Wood

The grain is formed by the distance between the annual rings.

Rapid growth produces coarse-grained wood, while slow growth produces fine-grain.

When the grain is straight and runs parallel to the pith, the wood is said to be straight-grained.

Often the rings are twisted round the axis of the tree causing spiral grain.

Frequently in wood several rings of fibres will run oblique to the axis of the tree in one direction and the next layers are oblique in the opposite direction. Such wood is known as cross-grained. Wavy-grain is caused by large undulations in the wood fibres, curly-grain by small undulations. Oak, ash and birch are often curly- or wavy-grain.

Straightness of grain is of great importance in wooden beams and tension members. Careful examination should be made to ascertain that this is the case, particularly for aeroplane construction.

Texture and Grain

Two sets of characteristics of wood that are very often confused are texture and grain. *Texture* refers to the relative size of the elements of which the wood is made up; *grain* to their direction and the width of the growth rings. In texture wood may be either coarse, fine, even or uneven. Coarse-textured wood has many of its elements large, as, for instance, chestnut. Fine-textured wood has its elements mostly small, as in willow or poplar. Even-textured wood is that in which the elements are uniform in size, as in box, cedar, horse-chestnut, etc.; uneven-textured, that in which the elements have marked contrasts in size, as when there is a great difference between early and late wood, such as pitch-pine, oak, chestnut, elm, ash, etc.

Structural Defects

Besides irregularities in the character of the grain, there are two important classes of defects in wood—knots and shakes.

Knots are where branches start. They affect the workability, shrinkage, and the strength of the wood. They destroy the continuity and consequently diminish the tensile strength. Such defects are a source

of weakness when present in a beam. They reproduce the compression strength about 20 per cent., dependent on the position of the knots.

Knots become loose when dry or dead, which is detrimental. In aeroplane construction wood containing knots is normally rejected.

Star-shakes are radial cracks produced by unequal stresses set up in the wood during the seasoning process.

Splits in the ends of boards—due to shakes or the boards not being banded during seasoning.

Fig. 5.—SHAPING THE AIRSCREW BY HAND.

The roughly shaped block is shown being shaved to the correct form by a skilled man. The true form is first obtained at pre-determined positions along the blade, and the whole shaped accordingly.

Cup-shakes are separations between adjacent rings. They are possibly due to the bending of the tree by the wind. They are generally invisible in green wood, but become apparent after seasoning.

Heart-shakes are radial cracks emanating from the pith in the trunks of very old trees. It is likely that shrinkage of the heartwood while the tree is still standing produces these defects.

Great care must be exercised in inspecting for shakes, as they are not always discernible until the wood is varnished.

Shakes adversely affect the durability of wood because they admit moisture and air.

Non-Structural Defects

Pitch pockets, dry rot, dote and worm holes are other defects of

wood which are not structural by nature. These defects have an important bearing on reliability.

Pitch pockets are openings between the annual rings, which contain resin, either in liquid or solid form. This resin is nature's method of healing holes, shakes, etc. Pitch pockets are seldom found in hardwood, but are common in conifers. They tend to bulge a normally straight grain, but are permitted in aeroplane wood provided they are very small.

Dry rot is the result of fungus attacking the wood, bringing about the death of the parts affected and possibly the entire tree. Dry rot may be detected by the crumbling of the wood when it is being worked and by the change of colour, or by the musty odour.

Dote is the commencement of wood decay, generally accompanied by dark brown spots scattered over the wood. The fibres are soggy and lifeless, breaking out in pieces when picked with a knife.

Worm holes. As the grub might still be alive, the wood should be rejected for aeroplane work.

Specific Gravity

The specific gravity of all types of dry wood substances has been found by experiment to be approximately 1·45.

The density or apparent specific gravity (the ratio of the weight of the wood to the weight of an equal volume of water) varies from 0·20 in the case of cork wood, to 1·36 for Indian anjan. The discrepancy between these figures and that for dry wood is due to the porosity of the wood structure.

A comparison of two woods, each containing the same percentage of moisture, will show the heavier to be the stronger ; this strength varying nearly directly as the weight.

The most reliable index of specific gravity without making an actual test is the ratio of spring wood to summer wood per annual ring.

In soft woods, to possess the necessary strength, each annual ring should have approximately one-third or more of summer wood.

In hard wood, such as ash, to possess the necessary strength, each annual ring should have about three-fifths or more of summer wood.

Mechanical Properties of Wood

The factors affecting the general strength of woods having been defined, their mechanical properties will now be considered. The suitability of any wood for a given purpose depends on these properties, which include stiffness, toughness, hardness, flexibility and its strength to resist the various stresses to which it may be subjected, such as compression, tension, bending, shearing, etc.

Stiffness

The amount that a piece of wood will bend under a given load is a

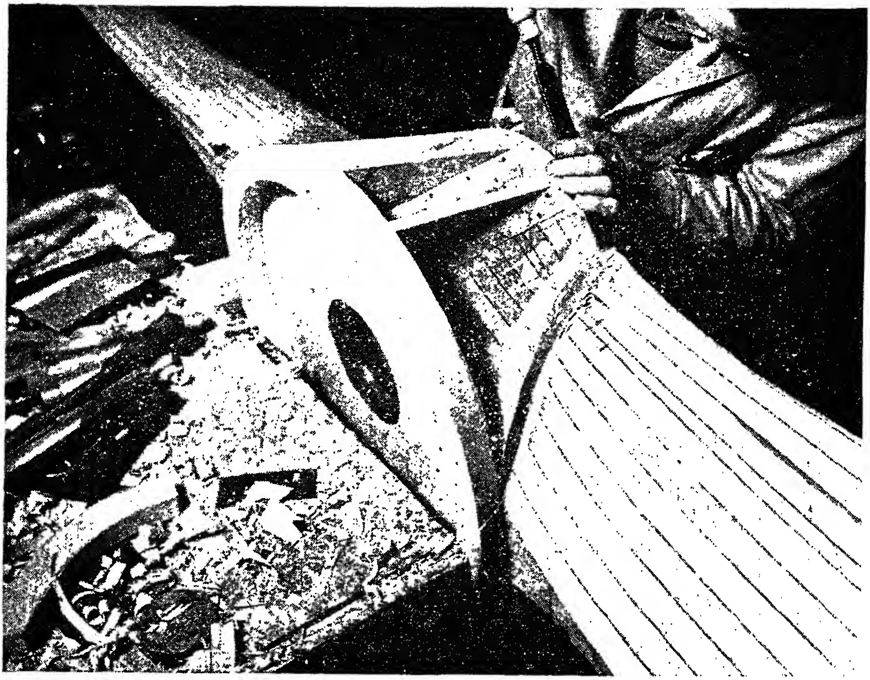


Fig. 6.—FITTING THE SPINNER.
This is a plywood cowl built up on ribs glued and screwed to the airscrew boss.

measure of its stiffness. It is usual to compare the stiffness of various kinds of wood by the formula for deflection of beams. Knowing the deflection, the loading and the dimensions of a piece of wood, its modulus of elasticity can be calculated and then compared with that for other woods. Softwoods are nearly as stiff as hardwoods and at the same time considerably lighter in weight.

Knots and other defects, as well as moisture, affect the stiffness of wood.

From the same tree the wood from the lower portion is stiffer and heavier than that higher up.

Toughness

Toughness is a word commonly applied to woods. The ability to withstand shocks is one characteristic of a tough wood. It must be strong and flexible, so that tough wood must possess at the same time considerable resistance to tension.

Hickory is a good example of a tough wood.

The tests used to indicate toughness are :—

(*a*) The determination of the " work done to maximum load " (often called resilience).

Fig. 7.—CHECKING THE SHAPE AND PITCH OF THE FINISHED BLADE.

The airscrew is mounted on a spindle, perfectly level. Note the spirit level, the section gauges on the bench and the tester operating a combined caliper and inclinometer.

(*b*) The resistance to impact, or the distance which a known weight must fall to cause complete fracture of the wood.

The first is generally expressed in inch-pounds per cubic inch.

Hardness

This gives an indication of the wear-resisting qualities of a wood.

A method of ascertaining the hardness is the weight per square inch required to produce an indentation of a certain amount.

Very hard woods require over 3,200 lbs. per square inch to produce an indentation of $\frac{1}{20}$ in., while soft woods require only about half this pressure.

Flexibility

This can be defined as its ability to bend very considerably without breaking. Due to greater fibre strength some wood can be bent a great deal without breaking. The ratio of bending strength to the modulus of elasticity is a good measure of the flexibility.

Pine is very brittle. Ash is an example of a flexible wood.

Compressive Strength

This depends upon the length and smallness of diameter of the specimen and also upon the direction of the grain. The resistance of a very short piece to compression is called its end-crushing strength.

This may be considered as independent of the smallness of diameter of the piece.

The compressive strength of wood across the grain is much less than that parallel to it. For oak it is less than a third as much, while for white pine it is only an eighth.

Tensile Strength

This depends on several features, the strength of the fibres, their adhesion to one another, the presence of pith rays, the direction and type of the grain and the presence of defects.

Tensile strength is not of as much importance as may be supposed, due to the fact that when wood is used as a tension member it will usually fail in some other way, sometimes the fastenings will pull out. The use of wood in tension should be avoided, but if this is impossible the calculation of strength should depend upon the strength near fastenings, or upon splitting, etc.

The tensile strength across the grain is only about 5–10 per cent. of that along the grain.

Bending Strength

Bending strength is affected by moisture, defects, direction or type of grain, etc.

Primarily, compression strength depends upon the strength of the fibres of the wood, hence the term "fibre strength." When wood is bent the fibres on one side are placed in compression and those on the other side in tension. A piece of wood having knots in it should, for this reason, be placed so that the knots come on the compression side if possible.

It is very necessary that the moisture content in wood, as well as the factor of safety to be used in designing, should be known before an accurate comparison of the bending strength can be made.

Shearing Strength

This depends upon the direction of the grain. Shearing across the grain is of little importance, other methods of failure being more liable to take place. Shearing parallel to the grain is very important. It occurs in the following ways :—

(*a*) Simple shearing, as when a bolt pushes out the wood in front of it, causing the fibres to slide over each other.

(*b*) Longitudinal shearing, caused by bending.

The latter is a very common form of failure in beams.

Softwoods—Characteristics of Different Woods

Pine.—The principal varieties of pine are white pine, yellow pine, pitch pine, etc.

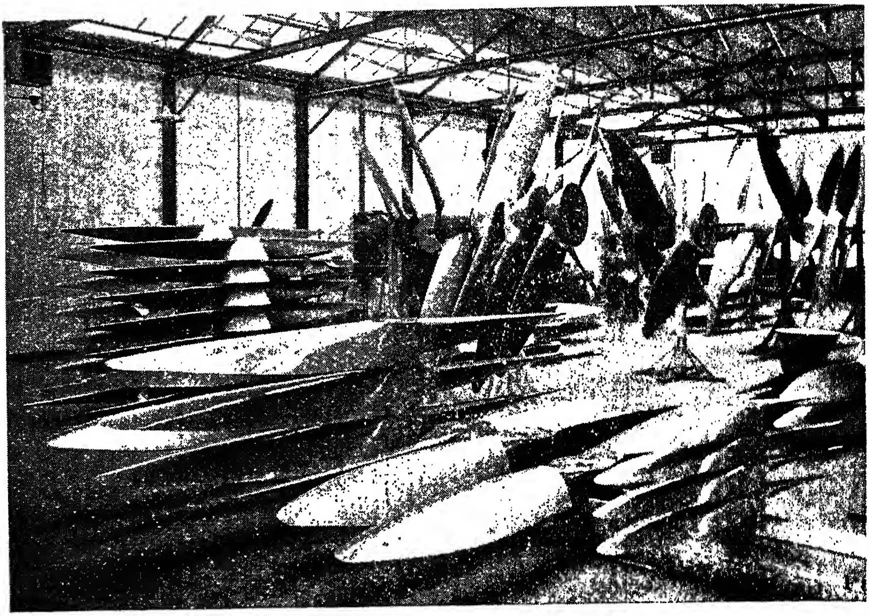


Fig. 8.—THE FINISHED AIRSCREWS AFTER SURFACING WITH SPECIAL CELLULOSE FINISH.

White pine is soft, straight-grained, easily worked and of light weight. It is not very strong and splits easily, but it is practically free from defects and when protected by paint is very durable. The other varieties resemble this white pine quite closely, but are not considered to be as good.

Spruce.—There are several varieties of spruce. It is very similar to white pine and fir. It is light, straight and close-grained, but is inclined to warp and twist. It has remarkable strength considering its light weight and this accounts for its extensive use in aeroplane construction. It splits easily and generally contains a large proportion of defects. White spruce is stronger than red spruce.

Fir.—This wood is similar to spruce and pine, but has no resin-ducts. It is light in weight, soft and straight-grained, but brittle. White fir has slightly more bending strength in proportion to its weight than white spruce.

Douglas fir, or Oregon pine, is really not a fir at all, but a species of hemlock. It is one of the most important of woods, being available in almost any size and also has great strength. For its weight it is stronger than pine and is not so stiff. The grain is rather spongy.

Cedar.—There are many varieties of cedar, which are sometimes classified as white, red and yellow.

Cedar is characterised by light weight and its soft and close grain. It is easily worked, but is brittle and splits easily. It is durable, resists

decay and absorption of water, shrinks very little, but is somewhat expensive.

Hardwoods

Oak.—There are a great number of different varieties of oak, but only a few of these are useful for constructional purposes. Oak is not liable to split under stress, holds fastenings remarkably well and can be bent.

Its disadvantages are its complicated structure, its weight and the fact that it is expensive.

Ash.—This is a very common hardwood, similar to oak, but more easily worked although coarser. There are several varieties, white, black, red, etc. White ash is not as heavy as oak, but is stronger in proportion to its weight and is more flexible. It does not shrink much and is fairly durable. White ash is the most valuable, the other species being weaker and coarser. It is used extensively in aeroplane construction.

Hickory.—There are numerous varieties of hickory. It is very heavy and remarkably strong. The grain is straight. It has great resistance to shock and vibration and is specially valuable for use in construction of vehicles.

Mahogany.—Mahogany is one of the most important woods. The mahogany from Central America is the only true mahogany. The wood is strong, durable, warps and shrinks very little, easy to work and takes a good finish.

CONDITIONING OF WOOD

Processes for Drying Wood

It is as essential to dry or "season" wood as it is to prepare steel by proper heat treatment. The reasons for drying wood are as follows:—

(*a*) To improve its strength and mechanical properties.
(*b*) To decrease shrinkage after incorporation in the structure.
(*c*) To reduce its weight.
(*d*) To increase its resistance to decay.
(*e*) To aid application of protective coatings.
(*f*) To facilitate working.
(*g*) To reduce the possibility of warping.

Water will not drain out of wood; therefore some means of evaporating it is necessary. It must be realised that it is impossible to eliminate all moisture from timber. If the water were entirely removed, the timber would re-absorb it from the surrounding atmosphere, about 10–12 per cent. of moisture being absorbed.

Factors Influencing Drying

Strength and stiffness are improved under proper conditions of drying. If drying is not carried out correctly the wood will be weakened as a result of uneven shrinkage.

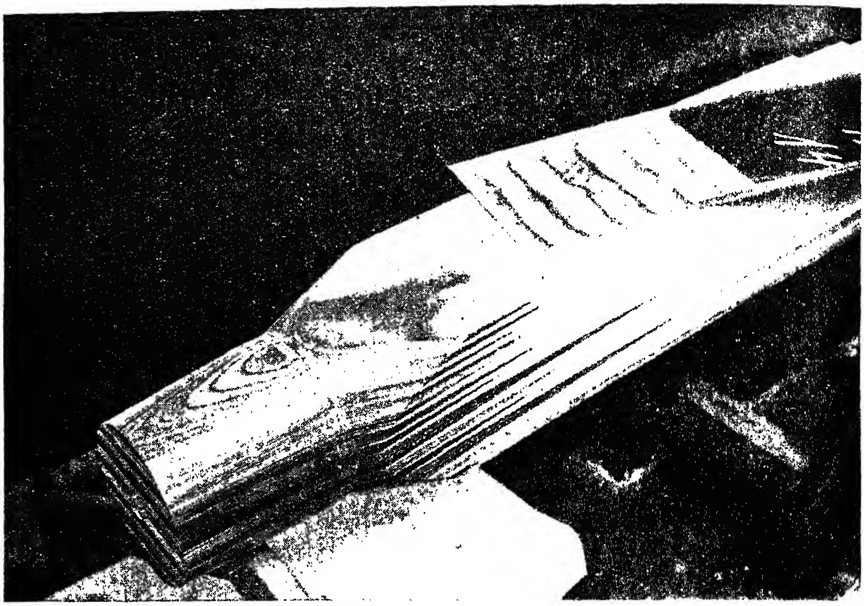


Fig. 9.—SHOWING THE USE OF COMPRESSED HARDWOOD FOR THE ROOT END OF A DETACHABLE BLADE.

The compressed wood is used only at the root of the blade. Note the scarf joints connecting the hardwood to the softwood.

Logs dry much more slowly if covered with bark, and are more likely to decay than those without bark.

Wood of large moisture content dries in about the same length of time as that of lower moisture content, due to the fact that the sapwood which contains most of the moisture dries more rapidly than the heartwood.

Boards lose most of the moisture through the sides.

Method of Drying

Two methods of drying are in general use—air-drying or "seasoning," and kiln-drying.

Temperature and humidity conditions have a vital influence on drying. In air-drying, which simply amounts to exposure of the wood to the atmosphere, no control over temperature and humidity is possible. Consequently the process is one requiring many months of exposure to the weather with the probability of losses of material as a result of warping, decay, etc. Such loss, however, is offset by the inexpensiveness of the process.

Advantages of Kiln-Drying

To air-dry fir requires from 12–18 months, whereas by kiln-drying

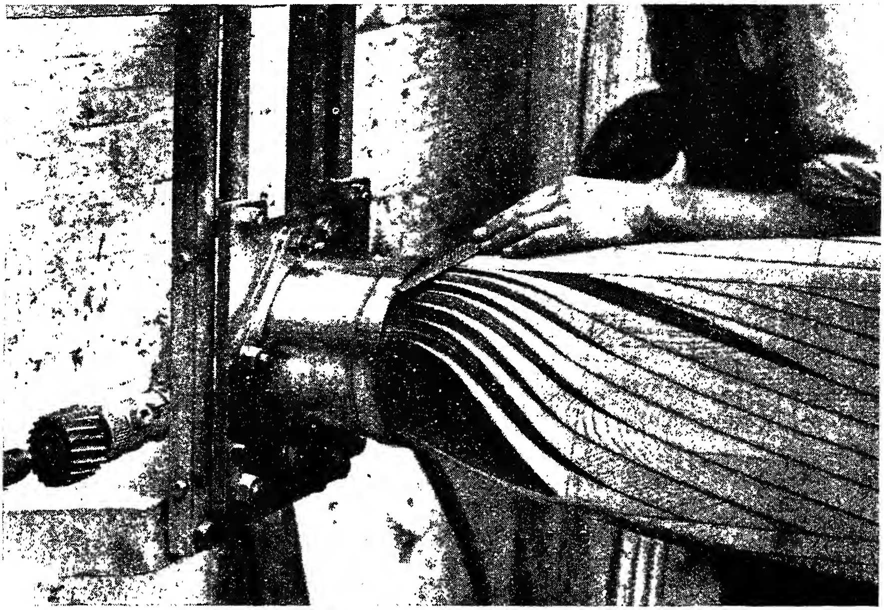


Fig. 10.—A DETACHABLE BLADE.

Showing the steel shoe which is fitted. Note the lines indicating the section positions for checking the shape.

only 18–24 days are necessary. To air-dry wood for airscrews takes from one to two years; to kiln-dry the same material takes approximately one month.

Wood can be more easily damaged in a kiln than when left to dry in a shed exposed to the atmosphere. Properly controlled, however, kiln-drying has the following advantages :—

(*a*) The time required for the process is only a fraction of that necessary for air-drying.

(*b*) Control is afforded over temperature, humidity and circulatiou of air, which obviates warping, splitting and uneven shrinkage.

(*c*) There is less subsequent warping and shrinkage.

(*d*) There is less likelihood of deterioration from attack by insects, or by checking and decay.

A large percentage of the wood used for aeroplane work is kiln-dried.

Kiln-Drying

A kiln is an enclosed room into which wood may be piled. It is fitted with steam radiators for supplying the heat, fans to blow on the radiators to afford the required circulation, and cocks, or taps, on the radiators to admit steam for regulating the humidity.

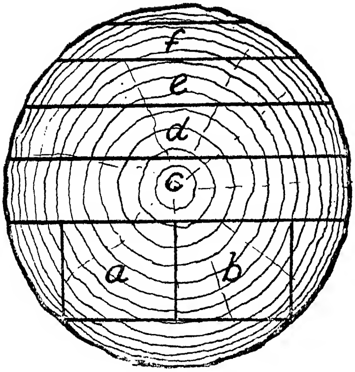


Fig. 11.—CONVERSION OF TIMBER
Showing a log cut into planks and beams.

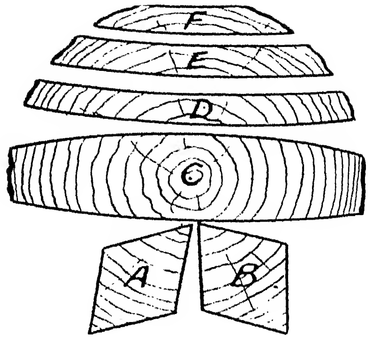


Fig. 12.—CONVERSION OF TIMBER.
Showing in exaggerated form the shrinkage subsequent to cutting.

One species of wood with approximately one thickness of material is the best practice when charging a kiln. The thickness variation should not exceed $\frac{1}{2}$ in. The boards are piled so that the width of the spaces between them is at least 1 in. for each inch of board thickness. This is done to afford proper circulation. In order that the boards will remain flat and straight while drying, separators are placed at intervals not exceeding 4 ft. These separators should be at least $\frac{1}{4}$ in. in thickness, not over 2 in. wide, and laid so that they will be directly over one another. The wood must be so disposed in the kiln as to permit of easy access on all sides of the pile, to make easy the reading of correctly located thermometers and hygrometers.

At the start of the drying process the humidity should be about 85 per cent., with a temperature of about 32° C.

As the wood dries the temperature is increased gradually to about 140° F., while the relative humidity is dropped to 45 per cent. A final temperature of 155° F. is required for a short time for the removal of the internal moisture.

Thermometers and hygrometers must be read at regular intervals and temperature and humidity gradually varied to obtain even shrinkage. Process samples should be withdrawn from the kiln and weighed to check the moisture content of the kiln charge during the process.

Any drying process depends upon the uniformity of drying and its effect upon the mechanical properties of the wood. This requires the rigid control of temperature, humidity and circulation of the air in the kiln. The circulation must be through the piles and not round the room and out of the exhaust. Uneven shrinkage, with resultant uneven stresses, occurs where kiln control is poor. If the outer surface dries faster and shrinks earlier than the interior, excessive tension in the outer fibres results, which may cause them to pull apart, developing cracks in the wood.

Where rupture, or pulling apart, does not occur, the outer fibres become set. Further shrinkage of the piece as a whole is therefore diminished.

This brings about a gradual reversal of stress in the shell and causes a radial tension in the interior. This condition is called case-hardening and must not occur in wood for aeroplane use, as distortion is bound to occur when it is cut. It may be rectified by steaming the wood at a temperature of not more than 20° F. above the final drying temperature, for a period not exceeding $3\frac{1}{2}$ hours, and then re-drying.

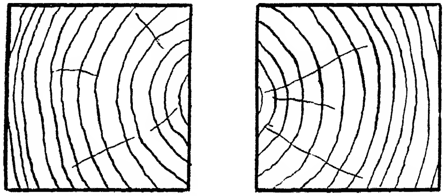


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Fig. 13.—CONVERSION OF TIMBER.

If the shape of rectangular pieces is to be preserved, they must be cut square with the centre of the tree.

High humidity and too high a temperature at the start of the drying process will cause the interior of the wood to dry out first, producing stresses within the wood. If these stresses become excessive the fibres are pulled apart, thus developing internal cracks called honeycombing, which destroys the wood as a material for aeroplanes.

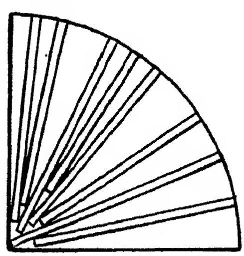
Kiln-dried wood must be exposed to uniform shop conditions at least two weeks for 3 in. planks and other sizes in proportion, prior to being worked.

This is to ensure that the wood will not distort, due to absorbing moisture in the shop whilst being worked.

Conversion of Timber

Conversion of logs is the operation of sawing them into planks, deals, battens, etc.; this is, as a general rule, done before seasoning.

The subsequent shrinkage is noticeable in the sections when cut. As an example, a log cut into planks and beams is shown in Fig. 11. The middle piece "*c*," when dry, will remain almost the same width and of the same thickness in the centre. The thickness of the edges will diminish a small amount and is shown exaggerated in Fig. 12 "C."



J

Fig. 14.—CONVERSION OF TIMBER.

If boards are required that will not shrink in width nor warp, they must be cut as shown above.

The piece *d* will take the shape of "D." Owing to the shortening of the rings, this piece will shrink in its width more on the top surface than the bottom surface next to the heart of the tree, giving the plank a curved shape as shown. This also will be somewhat thinner at the edges than in the middle; *e* and *f* follow

the same action as shown; the shrinkage in width is more marked, but they keep more parallel in thickness. The tendency to distort with rectangular-shaped pieces is shown in " A " and " B."

If their shape is to be preserved they must be cut square with the centre of the tree, as in Fig. 13 " G " and " H." If boards are required that will not shrink in width nor warp, they must be cut as shown in Fig. 14 " J."

Veneers

A veneer is a thin layer or sheet of wood cut from logs. In aeroplane construction veneers are employed in plywood. They are sometimes used for webs of wing ribs, fuselage coverings, and float decks.

The veneers commonly employed are birch, mahogany, cedar and ash.

Manufacture of Veneer

There are three methods of cutting veneer :—

(*a*) Rotary cutting.
(*b*) Sawing.
(*c*) Slicing.

Rotary Cutting.—Of these, the most common is rotary cutting. It consists of holding the log between centres in a lathe. As the log rotates a long knife is gradually moved towards the axis peeling off a strip of veneer of length equal to that of the log between centres and of width depending on the diameter of the log and the thickness of the sheet required.

Prior to cutting, the logs which vary from 4 to 8 ft. in length, are steamed if of hardwood or a heavy veneer is to be cut. Preliminary steaming is unnecessary with thin veneer of softwood.

Fig. 14 illustrates the manner in which the veneer is cut.

The maximum commercial length for rotary cut veneer is about 16 ft., due to greater unsupported lengths producing chattering, with resulting irregular and cracked surfaces. For birch, mahogany and ash a maximum thickness is about $\frac{1}{4}$ in. and a minimum thickness about $\frac{1}{64}$ in.

Sawing.—This method is by means of a special type of circular saw and operated so that the veneer will be pushed outward and over it in much the same manner as is done by the knife in rotary cutting.

The minimum thickness of the veneer by this method is at best $\frac{1}{25}$ in. and the maximum width is about 20 in.

Slicing.—Thinner veneer can be cut by slicing than by sawing and there is no wastage. The log is squared up after it is clamped to a base plate which is moved forward and downward against a stationary knife.

The minimum thickness of mahogany veneer by this method is about $\frac{1}{120}$ in. The maximum width is about 24 in.

Plywoods

Plywoods consist of a number of layers of veneer, of the same or of

different kinds of wood glued together so that their grains run at different angles. This construction offers the following advantages :—

(a) Greater resistance to warping, shrinkage, etc.
(b) Greater lightness for equivalent strength.
(c) Greater flexibility than stock of equal thickness.
(d) Greater homogeneity in the structure of the finished panel.
(e) Greater uniformity in mechanical properties.

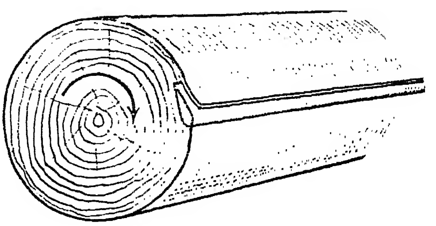


Fig. 15.—CUTTING VENEER.
This illustrates the manner in which veneer is cut from a log.

Proper symmetry is obtained by using an odd number of layers so arranged that any ply will have the grain of the next ply at right angles to it.

Some of the uses of plywood are :—

(a) Ribs of wings.
(b) Instrument boards, lockers, floor boards, etc.
(c) Surface coverings.
(d) Covering for fuselages, particularly in monocoque construction.
(e) Bulkheads in fuselages, floats and hulls.
(f) Decking and bottoms for floats and hulls.
(g) Engine bearers and stiffeners.

Manufacture of Plywood

Veneers used for plywood are dried to a moisture content of 10 per cent., leaving them flat and ready for trimming.

Trimming follows to ensure freedom from defects, large shears being used. The veneers are next sorted out to suit the different layers of the plywood to be made.

Glue is spread on the backs of the two face layers and without any great delay these are placed above and below the core, and the layers so assembled are ready to be placed in a press.

Each veneer is very dry at the time glue is spread upon the faces. The time between this spreading of the glue and the pressing operation is fairly short, so that each layer has little time to absorb moisture, In consequence, there will be no appreciable shrinkage across the grain with the consequent production of stresses.

The press consists of cast iron plates with flat faces, which are heated by means of steam circulated through the interior of each plate to about 200° F. The layers, coated with glue, are placed between two of these plates and the plates are then forced together by pressure, adjusted to the size of the panel being glued and to the pressure required per square inch

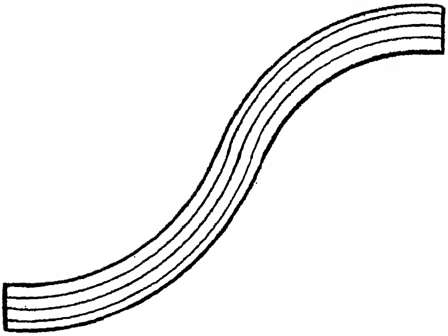


Fig. 16.—A STEAM BENT SECTION.

The wood used must be free from defects. Note the direction of the grain.

of its surface. The heat from these plates penetrates the face layers and sets the glue under pressure.

Steam Bending

Steam bending must be used for curved members where a continuity of fibres is required as in curved longerons, keels, frames and chines of hulls.

Steaming softens the fibres so that they will adjust themselves to the stresses produced in bending.

Experiments with the various woods reveal the fact that a number of them are not suitable for steam bending. Lightness, strength and hardness are essentials. As a result of the tests, ash has been shown to be superior to most woods for steam bending. Wood used must be free from structural and other defects.

The rough-worked material should be soaked in a hot water box before steam bending.

The amount of soaking is dependent upon the size and condition of the material as well as on the amount to which it is to be bent.

The steam-box is built of metal, with steam-tight doors at each end. The equipment consists of water and steam pipes, drain cocks, steam gauge and a means to control the doors.

The length of steaming depends upon the condition of the wood, its size and the angle of the bend required.

When soaked, the pressure of the steam forces the moisture into the wood at a rate corresponding to the pressure. From 15 to 20 minutes is an adequate steaming period for green sapwood, where a steam pressure of from 30 to 35 lbs. per square inch is maintained.

After steaming, the part is placed on the form used for bending.

Steaming should not be protracted, as the life is taken from the wood by too long a period in the steam-box.

Built-up laminated components are, however, more often used as they are stronger and less liable to alter in shape.

Use of Jigs

Various designs of jigs have to be employed, which depend upon the size and shape of the member required. Wood is ordinarily employed for the jig, since it is easily manufactured and altered to correct for spring of the member on removal.

The jigs used must be made for a certain amount of over-curvature.

Care must be exercised in bending the members over the jig to avoid undue strain.

Either metal or wood clamps are used to secure the member in the jig, and they should be placed at short intervals.

Several hours on the jig must elapse before the member is cooled and set.

When removed from the jig the open ends may be secured against springing or spreading by tacking a cross strip between the two ends. Drying requires several days, so that the parts should not be used for some time after steaming.

IRON AND STEEL

Before discussing at length the properties and characteristics of the more important metals which are used in the production of modern aeroplanes it will be useful to give a few definitions of the terms to be employed.

Definitions

Ductility.—The property of being permanently extended by a tensile or stretching force.

Tenacity.—The property of resisting fracture when under the application of a tensile force.

Malleability.—The property of being permanently extended or flattened when worked under the hammer or in the rolls. (Most metals are more malleable when hot than when cold.)

Toughness.—The power to resist fracture when subjected to bending, torsion or impact.

Brittleness.—The tendency of a metal to fracture on receiving a blow or shock. Brittleness implies lack of toughness.

Softness.—This is a relative expression for the property of permanently yielding to pressure without fracture.

Hardness.—A measure of the property in virtue of which a material is able to cut, scratch or indent another material. It may be described as the capability of resisting wear by abrasion, or the resistance to penetration.

Elasticity.—The capacity of a material to return to its original size and shape on removal of distorting forces.

Fusibility.—The capability of being melted. All metals are fusible. A substance that does not easily melt is termed refractory.

Conductivity.—The ability or capacity of a metal to conduct heat (thermal conductivity) or electricity (electrical conductivity).

Iron

Iron occurs in large deposits as oxides, sulphides and carbonates, and in smaller quantities in a great variety of minerals. Very few rocks

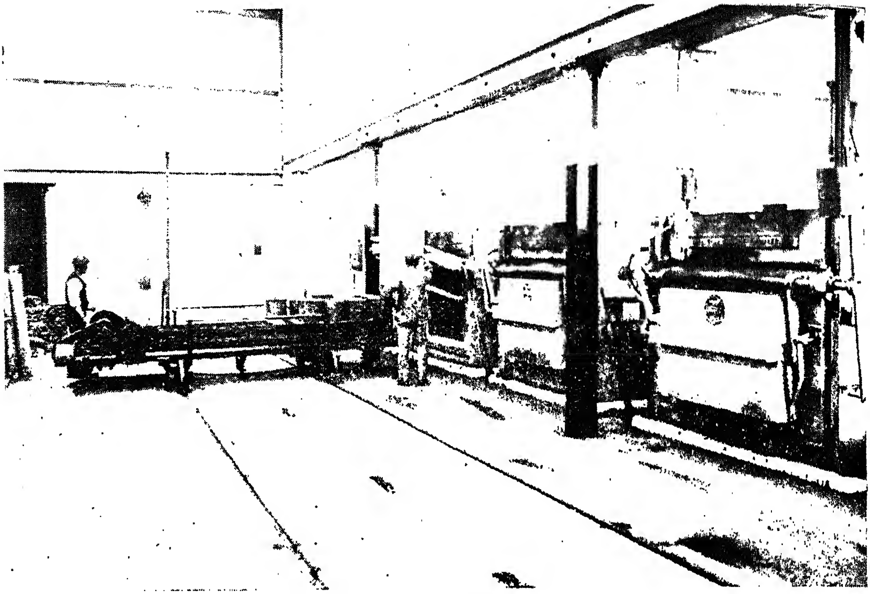


Fig. 17.—CASE HARDENING FURNACE.
A furnace being charged with pots containing components for case hardening.

or soils are entirely free of iron. Pure iron may be prepared by the electrolysis of a solution of iron sulphates. It is a silvery-white metal which melts at 2,780° F. It is ductile, malleable and almost as soft as aluminium.

Iron differs from most of the other metals in that the pure metal is seldom obtained. Iron containing small percentages of other elements exhibits a wide variety of properties which make it of the greatest value for aeroplane purposes.

Pig Iron

This is the material produced after the first reduction of the ore in the blast furnace. It is of no mechanical use, as it contains a high percentage of impurities which are subsequently removed by further processes. It is the base from which many kinds of iron and steel are made.

Cast Iron

The ores are mixed with a suitable flux and reduced by heating with coke.

The process is carried out in a cupola or blast furnace. The blast furnace is about 70 ft. high and 30 ft. in internal diameter at its widest part, narrowing towards the top. The walls are of steel and are lined with firebrick. The base has a number of pipes called tuyeres, through

which hot air is forced into the furnace. At the bottom is an opening, through which the liquid metal can be extracted. There is also a second opening above the bottom one, through which the slag overflows.

Charges consisting of coke, ore and flux in proper proportions are at intervals introduced into the furnace. The coke burns fiercely in the air blast, forming carbon dioxide, which is reduced to carbon monoxide as it passes over the highly heated carbon. Reduction begins at the top of the furnace through the action of the carbon monoxide.

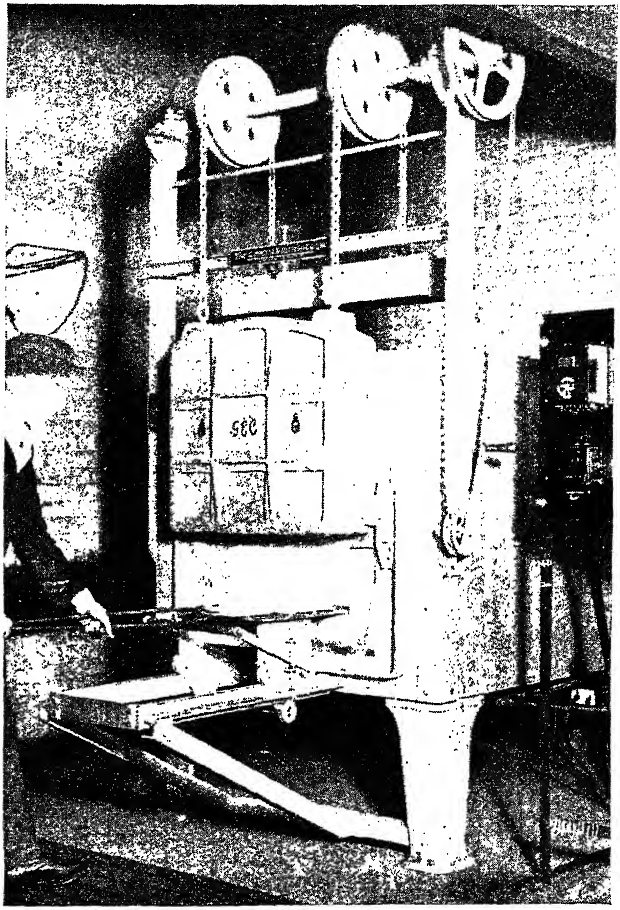


Fig. 18.—AN ELECTRICALLY HEATED FURNACE.
Note the roller track charging device.

As the ore slowly descends the reduction is completed, and the resulting iron melts and collects as a liquid at the bottom, the lighter slag floating on the top of it.

When a considerable quantity of iron has collected, the slag is drawn off and the iron is run into moulds and then taken to the steel furnaces for the manufacture of steel.

It is a brittle, non-malleable, non-ductile metal and cannot be forged, rolled, drawn or hammer welded, but can be fusion-welded. It cannot be hardened or case-hardened, but it casts extremely well. The condition of the carbon in cast iron varies. It can be held in a free or graphitic form, or in a combined state. When the free carbon percentage is high the metal is known as grey cast iron, and a fracture shows a coarse

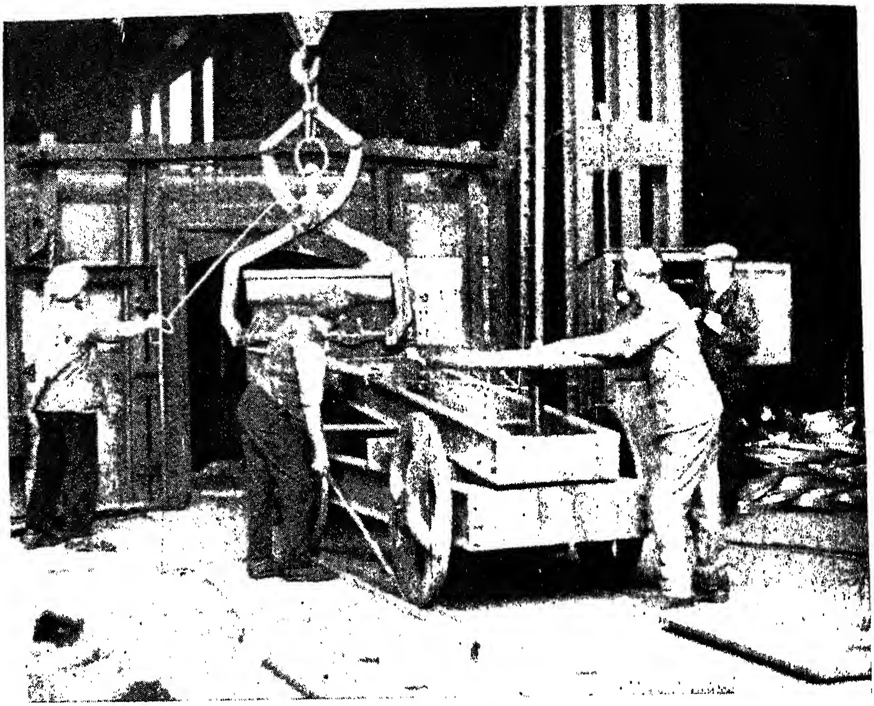


Fig. 19.—AN ANNEALING FURNACE.

Charging a cast iron pot filled with coils of wire into furnace for annealing. A number of such pots are placed on a rotating hearth in order to obtain uniformity of temperature during the annealing operation.

crystalline structure, grey in colour. When the percentage of free or graphitic carbon is low, *i.e.*, when the maximum amount of carbon is in the combined state, the metal is called white cast iron, and its fracture shows a finer structure, white in colour. White cast iron is much harder than grey cast iron. The melting point of cast iron varies around 2,010° F.

Chilled Cast Iron

Castings of this type can be produced by pouring the molten metal into a metal mould. This causes the castings to cool rapidly, whereby some of the carbon remains in a combined state, and the crystals are much smaller. Chilled castings are therefore very hard, especially on the outer surface of the metal.

Malleable Castings

Cast iron articles are sometimes made more shock resisting by prolonged heating in contact with an oxidising substance, whereby some of the carbon is oxidised. The metal is then termed "malleable cast iron."

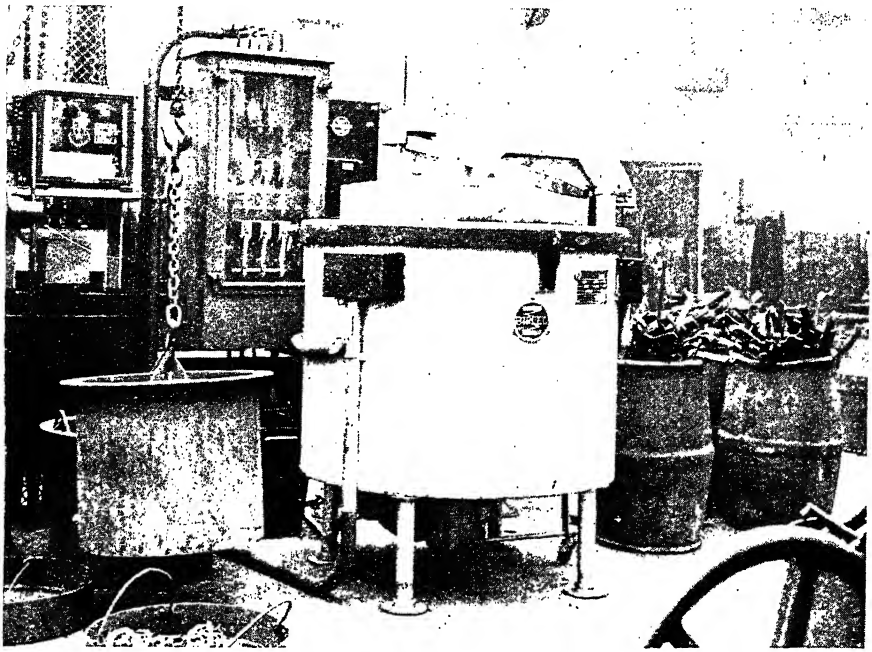


Fig. 20.—AN ELECTRICALLY HEATED TEMPERING FURNACE.

The pot for charging the furnace is shown on the left. Air circulation is provided during tempering to ensure uniformity of temperature.

Effects of Impurities in Cast Iron

Silicon.—Promotes the formation of free or graphitic carbon and has a softening effect.

Sulphur.—Opposes the formation of free carbon, and causes increased shrinkage and unsound, badly-defined castings. Good cast iron should not contain more than 0·1 per cent. sulphur.

Manganese.—Causes increased hardness. A casting that has an excess of manganese is very hard to machine.

Phosphorus.—This impurity increases the fluidity of the metal, but if in excess increases the brittleness.

Wrought Iron

Wrought iron is produced from cast iron by extracting most of the carbon, silicon, phosphorus and sulphur, the operation being conducted by what is called puddling in a reverberatory furnace. The charge consists of pig iron and old slag or iron oxide. After melting the charge, iron oxides are put in to remove the silicon and manganese and some of the phosphorus.

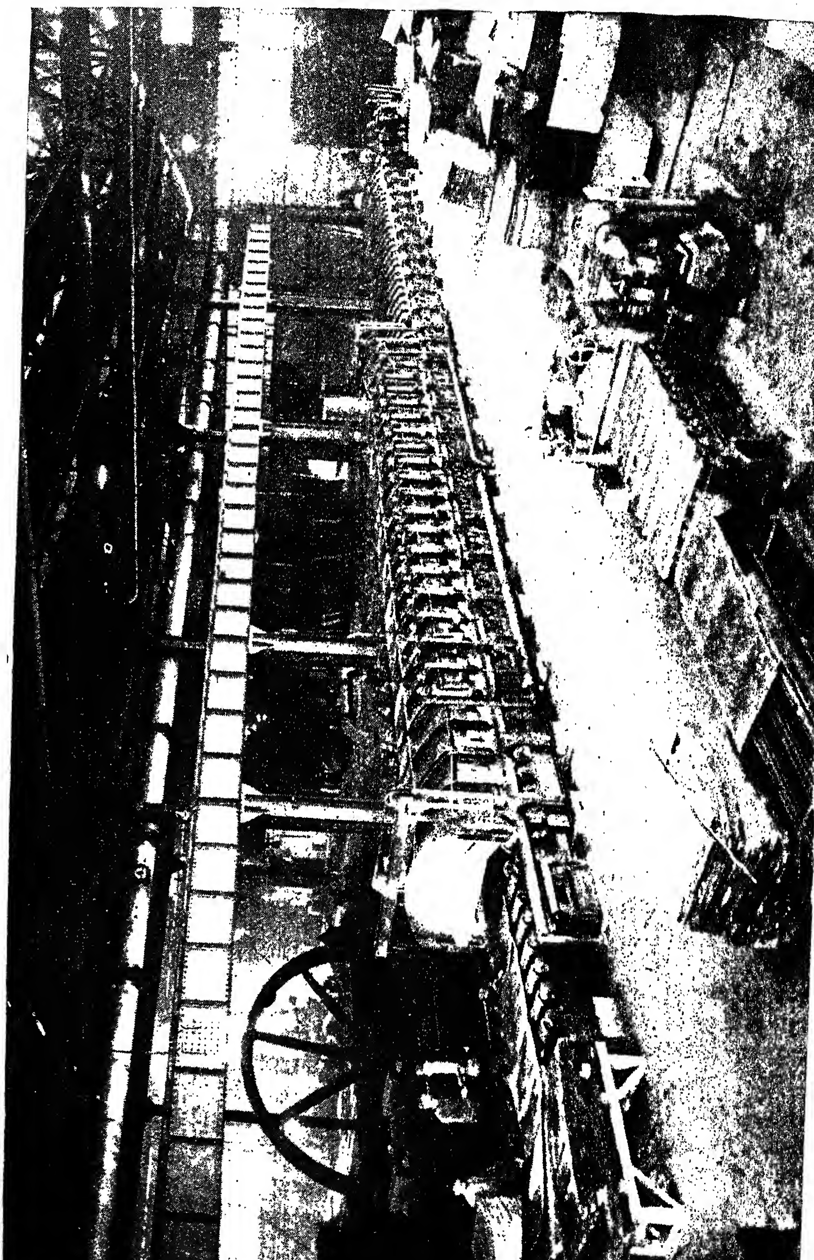


Fig. 21.—FURNACE FOR SHEET HEAT TREATING.
Note that the sheets are fed continuously into the furnace.

The furnace temperature, whilst high enough to melt the pig iron and keep the charge molten during the greater part of the time, is not sufficiently high to produce the refined product. It solidifies to a pasty mass, which can be worked into balls of about 150 lbs. in weight.

These balls are removed from the furnace covered with slag, the slag is fluid at this temperature.

This fluid slag is largely removed by a roller and squeezer and the ball is then rolled into bars. It is very malleable and ductile and can also be forged, extruded and hammer welded, the latter being a very important characteristic. It cannot be hardened as in the case of the higher carbon steels, but can be case-hardened. A torn fracture of the metal shows a remarkable fibrous structure due to the presence of slag about 2 per cent. maximum. It contains up to 0·2 per cent. combined carbon (maximum), has a tensile strength greater than that of cast iron, about 18–20 tons per square inch, and a compressive strength of 25–30 tons per square inch. It cannot be cast into shape. The melting point is about 2,760° F. It is no longer produced to the same extent as previously, since soft steel can be made at less cost and is well adapted to almost all the uses for which wrought iron was used. It is required where resistance to corrosion must be high.

Steel

Steel is made from cast iron by extracting part of the carbon, silicon, phosphorus and sulphur. Nearly all steel is made by one of two methods, known as the Bessemer process, and the open-hearth process.

In the Bessemer process the furnaces are lined with dolomite, which extracts from the cast iron the carbon, silicon and phosphorus.

It is carried out in huge oval-shaped crucibles called converters, the size being such as to hold approximately 30 tons of metal. The converter is built of steel and is mounted on trunnions, so that it can be tipped over on its side for filling and emptying. A pipe is connected with an air chamber, which is at the bottom of the converter. The bottom is perforated, so that air can be forced in by an air blast.

White-hot liquid cast iron from the blast furnace is run into the converter through the top, the converter being tipped over to receive it. The air blast is then turned on and the converter is returned to a vertical position. The carbon, manganese, phosphorus and silicon in the iron are rapidly oxidised. The heat of the reaction, largely due to the combustion of silicon, keeps the iron in a molten condition. The air blast is continued until the character of the flame shows that all the carbon has been burned away.

When this process is complete, the desired quantity of carbon is added and allowed to mix with the fluid.

The converter is then tilted and the steel run into the moulds, and the ingots so formed are hammered or rolled into shape.

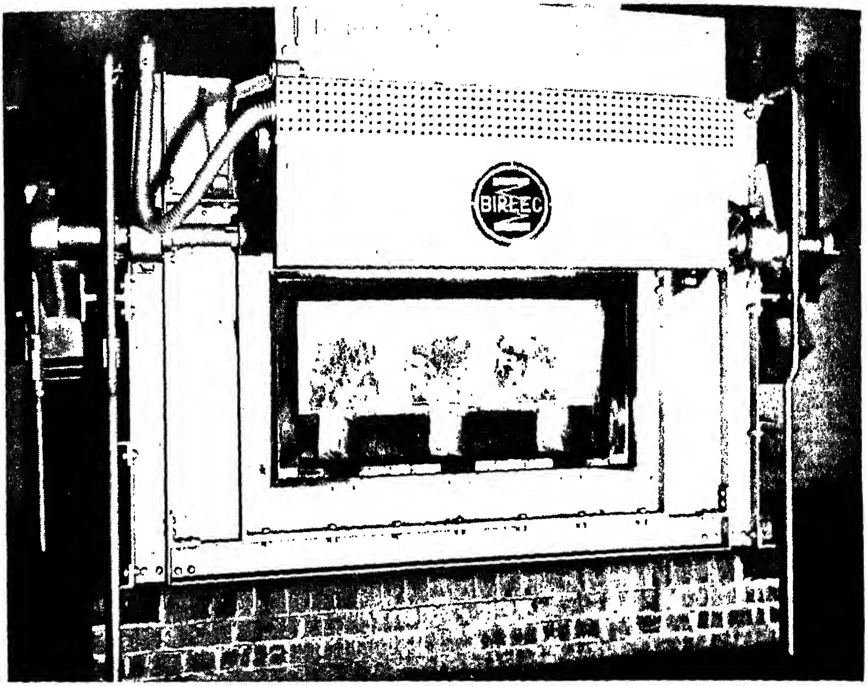


Fig. 22.—INSIDE VIEW OF AN ELECTRICALLY HEATED CASE HARDENING FURNACE.

By some, this process is considered obsolescent.

In the open-hearth process the lining of the furnace is made of silicon or dolomite. The hearth of the furnace is about 35 ft. in length, 10 ft. in width and 2 ft. in depth.

Pre-heated producer gas, or finely powdered coal is used as fuel.

Below the furnace is placed a brick checker-work, so arranged that the hot products of combustion escaping from the furnace may be conducted through it, heating the bricks to a high temperature. The air necessary for combustion is pre-heated by passing through the hot bricks, so that the temperature reached during combustion is raised considerably.

The gas entering the hearth mixes with the hot air and vigorous combustion takes place, the flame passing above and over the cast iron and lime with which the furnace is charged. At the temperature reached, the carbon in the cast iron is removed in the form of the oxide. The silicon, phosphorus and sulphur unite with oxygen and lime to form a slag which rises to the surface of the melted charge and is easily removed.

When a test shows that the desired percentage of carbon is present, the melted steel is run into moulds.

High grade tool steel is now being produced in electrical furnaces.

The current is used merely to produce heat, so that the process is not dependent upon electrolysis.

This method is almost identical with the open-hearth method, except in the way in which the heat is supplied, and it produces the same kind of steel.

Steel which owes its distinctive properties to its carbon content is termed " straight carbon steel." It is a compound of iron and carbon in varying proportions, and its strength depends upon its purity and upon the amount of carbon it contains. Straight carbon steel is usually divided into three classes as follows :—

Up to 0·25 per cent. carbon . .	Low carbon or mild steel
0·25 per cent.—0·7 per cent. . .	Medium carbon steel
0·7 per cent.—1·5 per cent. . .	High carbon steel

The medium and high carbon steels have the important characteristic of being made very hard by heating to redness and cooling suddenly. The degree of hardness resulting from this treatment depends upon the carbon content and upon the rate of cooling, and on the cooling liquid used. The low carbon steels, or mild steels, are not much affected by this hardening treatment, due to the low carbon content ; but the hardening value increases rapidly as the percentage of carbon increases.

The low and medium carbon steels can be forged, rolled and hammer welded, but as the carbon content increases, these operations become more difficult. The melting point of steel varies according to the carbon content (between 2,550° F. and 2,730° F.), the carbon having the effect of lowering the melting point.

General Range of Carbon Steels

Tools and parts to withstand heavy shock must be hard. The carbon content, therefore, should range between 0·8 per cent. and 1·2 per cent. For extreme hardness and where shock is not met the carbon content may be from 1·2 per cent. to 1·5 per cent.

For structural work mild steel should be used of about 0·2 per cent. carbon content.

Carbon Steels

Carbon combines easily with iron. The carbon of the pig iron, which may be over 4 per cent., is oxidised during the conversion process. This necessitates recarburisation of the steel to the amount desired by the addition of carbonaceous material. Low carbon steels, those which have less than 0·25 per cent. of carbon, are readily weldable, incapable of being hardened other than by case-hardening, are similar to iron, being tough and ductile though more homogeneous, and hence more reliable. Steels with 0·25 per cent. to 0·5 per cent. carbon are termed mild or medium carbon steels. They are not as easily welded as low carbon steels, but

can be hardened to some extent and exhibit greater strength. The high carbon steels, *i.e.*, those having 0·5 per cent. or more of carbon, give increased strength and hardness with increase in carbon content, but at the sacrifice of ductility and weldability.

Carbon steels usually contain four chemical elements in addition to iron and carbon.

(*a*) Manganese.
(*b*) Silicon.
(*c*) Sulphur.
(*d*) Phosphorus.

Of these the first two are of value, as they improve the properties of the metal.

Manganese.—This is the most important element in steel. It de-oxidises ferrous oxide, which is harmful, and combines with the sulphur to form manganese sulphide, the latter an impurity relatively harmless in small amounts.

Silicon.—Silicon in ordinary amounts is used in steel manufacture. as a scavenger. It is useful in that it eliminates gases, thus making the metal sound and free from blow-holes. Only small amounts of silicon are added, a fraction of that added is found in the finished steel, seldom exceeding 0·25 per cent.

Both silicon and manganese are introduced into iron in the smelting of the ores. Nearly all these elements are lost when the iron is converted into steel. It is therefore necessary to add them to the molten metal before being run into moulds. Ferro-manganese and ferro-silicon are employed for this purpose.

Sulphur.—This is valueless to the metal and so is kept as low as possible in all steels. Sulphur above 0·06 per cent. should not be present in steels, or the steel will become very brittle and red-short, *i.e.*, the condition of iron and steel in which it cannot be worked by hammering or rolling *at or above* a dull red heat.

Phosphorus.—This impurity should not be present above 0·06 per cent., or the steel will become cold-short, *i.e.*, the condition of iron and steel in which it cannot be worked by hammering or rolling *at or below* a dull red heat.

In the next section we shall discuss the various classes of steel used in aircraft construction.

STEELS USED IN AIRCRAFT CONSTRUCTION

Steel Castings

Low carbon (mild) steel can be cast into shape with varying success, but the higher carbon steels cannot be cast unless alloyed with certain other metals.

Cast Steel

The name is used to signify that the particular steel has been melted in a crucible and has then been cast into ingots. It is often termed "Crucible Cast Steel" and generally applies to a high carbon steel. After being cast into ingot form it is subsequently forged or rolled into the required bar or sheet.

Tool Steel

Any straight carbon steel that has been crucible made can be called tool steel providing the percentage of carbon exceeds 0·7. Sheer steels and the "open-hearth" steels can never be termed tool steels, as they are as a rule unsuitable for tool making. The tool steels used for lathe tools, milling cutters, drills, etc., are high carbon steels with a carbon content of sometimes 1·2 per cent.

High Speed Steels

These are alloy steels and are so called because they are capable of cutting at a much higher speed and greater depth than a straight high carbon steel.

The chief elements alloyed are chromium (Cr.), tungsten (W.), manganese (Mn.), vanadium (V.), cobalt (Co.) and molybdenum (Mo.).

Spring Steel

The name given to steel particularly suitable for spring making if it is correctly heat treated. It is usually a straight carbon steel of 0·9 per cent. carbon content, but a small percentage of vanadium is often added in aero engine practice for high-class springs, giving greater resistance to fracture, and increased resilience.

Stainless Steel

This class of steel is used particularly for parts subjected to duty where corrosion is possible. They have physical properties similar to those of high grade alloy steels. The chief alloying element is chromium from 12 per cent. to 20 per cent. with varying percentages of nickel. Forging and rolling are done at high temperatures with these steels, generally between 4,150° and 4,300° F., for below 3,170° F. these alloy steels begin to resist alteration in form. In addition to forging and rolling, these stainless steels can be cast, pressed, machined and hammer welded.

COMPOSITION OF AIRCRAFT STEELS

Aircraft Specification No.	Description.
3S1	Bright steel bars
2S2	55 ton alloy steel bars
2S6, S23, K5	" 40 " Carbon steel (normalised)
S8	45 ton alloy steel bars (heat treated)
S9, S10	3 per cent. Nickel steel
3S11, S12	55 ton Nickel-Chrome steel
2S14	Carbon case-hardening steel
3S15	3 per cent. Nickel steel
3S17	5 per cent. ,, ,,
—	2 per cent. ,, ,,
2S21	" 20 " Carbon steel
S26, S27	" 40 " Carbon steel (heat treated)
2S28	Air hardening Nickel-Chrome steel
—	100 ton oil hardening Nickel-Chrome steel
—	" 30 " Carbon steel (heat treated)
S33, S34, K1	60 ton Nickel-Chrome steel
S36	Chrome or Chrome-Vanadium steel
S61	High Chromium steel (non-corroding) 35/45 tons
S62	,, ,, ,, ,, ,, 46/52 ,,
S65	65 ton Nickel-Chrome steel
S67	5 per cent. Nickel case-hardening steel
S68	16 per cent. Tungsten steel
S69	3½ per cent. Nickel steel
S70	" 55 " Carbon steel (normalised)
S71	" 30 " ,, ,, ,,
S76	" 40 " ,, ,, (hardened and tempered)
S77	" 30 " ,, ,, ,, ,, ,,
S79	" 55 " ,, ,, ,, ,, ,,
S80	High Chromium steel (non-corroding) 55 tons
S81	65 to 75 ton Nickel Chromium Steel
S82	Nickel Chrome case-hardening steel
S83	High tensile 5 per cent. Nickel case-hardening steel
K4	" 50 " Carbon steel (normalised)
K8	High Tungsten valve steel
K10	3 per cent. Nickel valve steel

MADE TO B.S.I. SPECIFICATIONS

Chemical Analysis (per cent.).

C.	Si.	S.	P.	Mn.	Cr.	Ni.	Other Elements.
·15–·40	·30	·05	·05	·50–·90	—	—	—
—	—	·05	·05	—	—	—	—
·35–·45	·30	·05	·05	1·20 max.	—	1·0 max.	—
—	—	·05	·05	—	—	—	—
·25–·35	·30	·05	·05	·35–·75	·30 max.	2·75–3·50	—
·25–·35	·30	·05	·05	·45–·70	·50–1·00	3·0–3·75	Mo. V. W. (optional)
·10–·18	·30	·05	·05	·90 max.	—	—	—
·10–·15	·30	·05	·05	·20–·60	·30 max.	2·75–3·50	—
·15 max.	·30	·05	·05	·40 max.	·30 max.	4·50–6·0	—
·15 max.	·30	·05	·05	·60 max.	·30 max.	1·50–2·25	—
·25 max.	·30	·05	·05	1·0 max.	—	·20 max.	—
·35–·45	·30	·06	·06	·40–·80	—	1·0 max.	—
·25–·32	·30	·05	·05	·35–·60	1·0–1·50	3·75–4·50	V. Mo. W. (optional)
·35–·42	·30	·05	·05	·45–·65	·75–1·25	1·25–1·75	—
·25–·35	·30	·06	·06	·40–·80	—	—	—
·32–·38	·30	·05	·05	·45–·70	·50–1·00	3·0–3·75	—
·35–·45	·30	·05	·05	·50–·80	1·0–1·50	—	V. ·25 max.
·15 max.	·50	—	—	—	12·0 min.	1·0 max.	—
·15–·35	·50	—	—	—	12·0 min.	1·0 max.	—
·22–·28	·30	·05	·05	·35–·65	1·0–1·40	2·75–3·50	Mo. V. W. (optional)
·08–·14	·30	·05	·05	·35 max.	·10 max.	4·60–5·20	—
·55–·70	—	—	—	·40 max.	3·50 min.	—	W. 14·0 min. V. 1·0 max.
·35–·45	·30	·05	·05	·50–·80	·30 max.	3·25–3·75	—
·50–·60	·30	·05	·05	·40–·75	—	—	—
·25–·35	·30	·05	·05	1·20 max.	—	—	—
·35–·45	·30	·05	·05	1·20 max.	—	1·0 max.	—
·25–·35	·30	·05	·05	1·20 max.	—	—	—
·50–·60	·30	·05	·05	·40–·75	—	—	—
·25 max.	·50	—	—	1·0 max.	16·0–20·0	1·0 min.	—
·28–·35	·30	·05	·05	·45–·70	·50–1·30	3·0–3·75	Mo. V. W. (optional)
·18 max.	·30	·05	·05	·50 max.	1·0–1·60	4·0–4·50	Mo. V. W. (optional)
·16 max.	·30	·05	·05	·40 max.	·30 max.	4·75–5·50	Mo. V. W. (optional)
·45–·55	·30	·06	·06	·40–·80	—	—	—
·55–·70	—	—	—	·40 max.	3·5 min.	—	W. 14·0 min.
·25–·35	·30	·05	·05	·35–·75	·30 max.	2·75–3·50	—

[*By courtesy of Hadfields Ltd.*

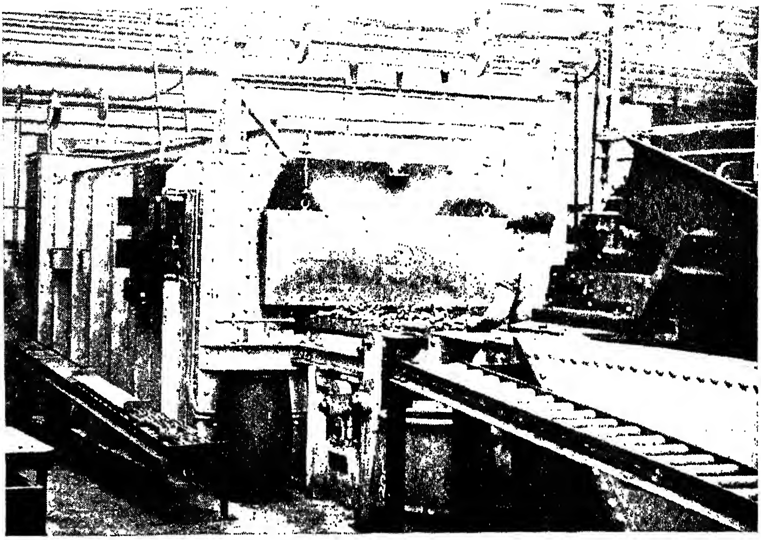


Fig. 23.—CONTINUOUS NORMALISING OF ENGINE PARTS.

The parts are fed in cold at one end and discharged at the opposite end at the temperature.

Alloy Steels

The term "alloy" steel is rather a misnomer, for there is no so-called carbon steel which is entirely free from elements other than carbon.

Carbon steels invariably contain small percentages of silicon, manganese, sulphur and phosphorus, and it has been found that the presence of small quantities of silicon are a distinct advantage; and the same applies to manganese. Both of these elements are usually kept below 1 per cent. in *carbon* steels. When other elements are introduced, even in small amounts, the properties of the steel are noticeably altered. These steels are usually termed alloy steels, and they possess peculiar strength and fatigue-resisting qualities, which render some of them very suitable for aeroplane work. Superiority in strength-weight ratio over other steels has been the principal cause for adoption. The tables on pages 66 and 67 show the chemical constituents (expressed as percentages) of aircraft steels conforming to British Standard Institution Specifications.

The Effects of the Addition of Some Elements

Nickel.—Nickel is added to steel in quantities varying from 2 per cent. to 40 per cent. The addition up to·5 per cent. to ordinary low carbon steel has the effect of raising the elastic limit and increasing the toughness, this latter feature being very important. Three per cent. and 5 per cent. nickel steels are extensively used for parts that require

case-hardening, because of the increased toughness of this steel over ordinary low carbon steel or iron. These steels of 3 per cent. and 5 per cent. nickel addition, are slightly harder than straight low carbon steel, but can be readily machined, and when hot, can be forged and rolled. Bars of steel containing about 20 per cent. nickel have a very high tensile strength and can be bent double without any signs of cracking. When the nickel content reaches 27 per cent., the alloy becomes non-magnetic and almost non-corrodible. Steel containing 36 per cent. nickel, called "INVAR," is largely used in the manufacture of scientific instruments, clocks, etc., for the reason that changes of temperature produce less expansion and contraction than in any other known metal or alloy.

Nickel and Chromium.—The addition of nickel and chromium to low carbon steel imparts the following valuable properties :—High elastic limit, with high ductility, great resilience with better wearing qualities than carbon steel.

Steels which contain nickel and chromium in varying quantities can be grouped in three classes, termed Nickel-chrome steels, and contain approximately :—

	Per cent.	Per cent.
(*a*) Mild Ni.-Cr. Steel	Ni. 3–5	Cr. 0·5–0·8
(*b*) Medium Ni.-Cr. Steel	Ni. 3–5	Cr. 0·8–1·0
(*c*) Air-Hardening Ni.-Cr. Steel	Ni. 3–5	Cr. 1·0–1·5

When the chromium content is above 12 per cent. the alloy becomes non-corrodible and is called *Stainless Steel.*

Vanadium.—This element is added in small quantities to steel to impart fatigue-resisting characteristics. Steels and alloy steels which contain about 0·25 per cent. possess an extremely high elastic limit and are exceedingly tough. Steels which are subjected to high alternating stresses and severe shock, such as aero engine valve springs, "Oleo" undercarriage springs, contain about 0·2 per cent. vanadium. The front axles of several well-known cars are made of steel forgings containing a small amount of vanadium.

The addition of 0·2 per cent. vanadium to ordinary low carbon steel has the effect of increasing the elastic limit and the toughness by about 50 per cent.

Tungsten.—The addition of tungsten to carbon steel and other alloy steels enables the alloys to be hardened to a high degree. Most "High Speed" steels contain tungsten, as it is this element more than any other which enables these steels to be used for high speed machining work.

In certain known quantities it imparts "air-hardening" properties and for this reason is frequently used for aero engine exhaust valves. It has the property of retaining its strength and hardness at dull red heat. If tungsten is added to the amount of 15 per cent. to carbon steel it is then impossible to machine by the usual methods ; 8 per cent. tungsten

content will render steel sufficiently hard to scratch glass. A high carbon steel containing 6·0 per cent. tungsten, with other alloying elements, is largely used for magnets, as it retains its magnetic properties much longer, and gives a " field " more intense than ordinary carbon steel.

Manganese.—Manganese added to steel will also impart exceptional hardness. Should the manganese content be about 5 per cent. the steel is very hard, but so brittle as to be practically worthless. But when manganese is present from 11 per cent. to 15 per cent. the steel becomes exceptionally hard and is tough instead of brittle. It is very difficult to machine with this manganese content and forges only with difficulty. Casting is the most satisfactory method of shaping this material. Steel containing a high percentage of manganese is used for jaws of stone-breaking machines; armour-plating steels also contain 11–15 per cent. manganese. Burglar-proof safes, railway and tramway curves are also made of a steel containing manganese up to 15 per cent. Steel containing over 5 per cent. manganese is non-magnetic.

Cobalt and Chromium.—When these elements are alloyed with carbon steel, special characteristics are imparted, such as non-scaling at high temperature, non-corrodibility, and air-hardening. This alloy is often used because of these properties for aero engine valves and special exhaust manifolds. Both cobalt and chromium are alloyed with high carbon steel to produce a high speed steel for special cutters, dies, etc., because of the air-hardening and exceptional cutting power of the alloy steel.

Cobalt.—The addition of cobalt to a high carbon steel produces an alloy which has exceptional magnetic properties. A permanent magnet made of 35 per cent. cobalt steel is capable of giving a " field " about three times as intense as that of a tungsten alloy, and about eight times that of a high carbon steel.

Molybdenum.—Has an influence on the physical properties and on the structure of steel similar to that of tungsten, but four times more intense.

When added to nickel-chrome steels, molybdenum has the effect of preventing temper brittleness.

Molybdenum increases the resistance to mineral and organic acids.

Mechanical Properties of Steel

The mechanical properties of steels, as with all materials, primarily determine the suitability for specific purposes. Practically all steels used in aeroplane construction have less than 0·9 per cent. carbon. The carbon content is the result of tests, by which the correct combination of strength, elasticity, hardness and workability have been estimated and found to be suitable for a particular service.

The Tensile Strength increases with carbon content up to approximately 1 per cent. So also does the hardness.

Tensile strength is defined as the maximum load required to fracture a specimen of the material, divided by the original area of cross-section.

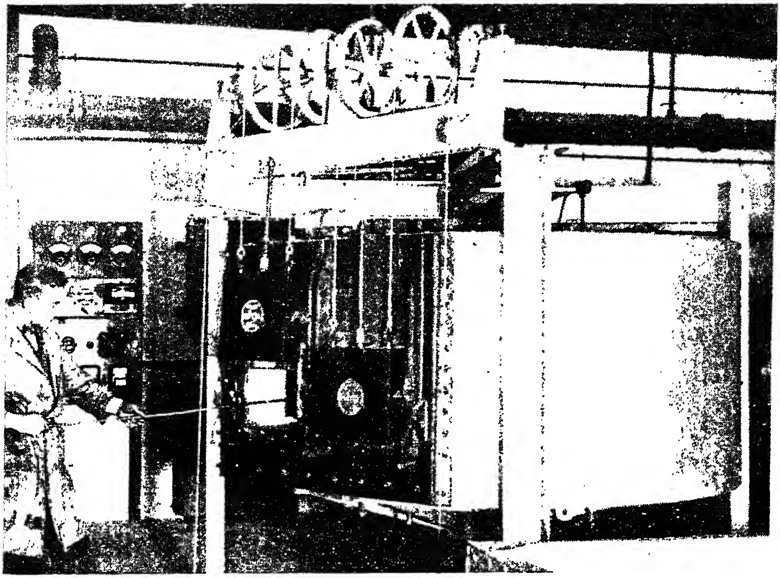


Fig. 24.—OPERATING A FURNACE FOR HEAT TREATMENT.
The hearth rotates in order to give uniformity of results.

Yield Point.—The load per square inch at which, when the load is increased at a moderately fast rate, a visible increase occurs in the distance between two points originally marked on the test piece. The yield point increases with the carbon content.

The Elastic Limit increases with the carbon content. The elastic limit is the maximum stress the material will bear continuously applied for an indefinitely long period without continually increasing strain.

The Shearing Strength.—The ratio of shearing strength to tensile strength is approximately 0·8 for low and medium carbon steels, but decreases as the carbon content increases, being in the vicinity of 0·6 for high carbon steels.

The Modulus of Elasticity is nearly the same for tension and compression, and for either stress it is practically independent of the carbon content. The modulus of elasticity is the weight in pounds which would stretch or compress a bar of sectional area of one square inch by an amount equal to its own length.

Fatigue.—The diminishing resistance to fracture caused by continued application of alternating or varying stresses.

Elongation.—The difference in the distance between two points before and after breaking of the test piece by stretching. It is usually expressed as a percentage of the original distance between the set points.

Factor of Safety.—The factor of safety is the ratio between the ultimate stress and the working stress.

Load Factor.—Used only in connection with aeroplanes, as the ordinary engineering safety factor is not feasible. It is usually the ratio of the breaking stress of the parts to the load carried in normal level flight. This factor provides the necessary strength for manœuvres, but does not necessarily include any margin when conditions for maximum possible stress are imposed.

Defects in Steel

Impurities and foreign matter have a great effect on the quality of steel, even if present only in minute quantities. These are introduced into the steel at some stage of melting and refining, or at some stage during hot working. Most of the defects originate in the melting furnace or ladle prior to pouring.

Reaction Products

The extent to which solid non-metallic items are included in the finished product depends on the nature of the process and, to a great extent, on the care used in melting and refining. The reaction products found are chiefly manganese silicate and ferrous silicate. Manganese oxide and ferrous oxide are not common, but affect the quality of the steel and its mechanical properties to a great extent.

Slag

Solids, such as slag, may be introduced mechanically through contact with the slag, ladle linings, etc. Proper care in the maintenance and repair of furnaces and ladles obviates much of this.

Occluded or Dissolved Gases

Most steels will contain traces of occluded or dissolved gases, principally hydrogen, nitrogen and carbon monoxide, though oxygen and carbon may also be present. During the mushy stage, the metal in the moulds is too viscous to allow the gas bubbles to escape, with the result that on solidification these bubbles form cavities in the ingots known as blow-holes.

In carbon steels the harm that may result from blow-holes depends largely upon their location. If deep-seated, the blow-holes will close and weld during hot rolling, thus eliminating the defect.

Ingot Defects

A cavity due to contraction occurring in that portion of the ingot which solidifies last is one of the most common defects.

Sound steel will always have this to some extent, and if absent, blow-holes will nearly always be found. To operate against this evil in the

finished product, mould design and control in pouring aim at having it in the top of the ingot, which can then be removed by machining.

Cracks and scabs are also ingot defects. The former result from contraction of the metal in immediate contact with the cold mould. The latter are produced by particles of molten metal splashing against the mould wall in pouring, and there solidifying.

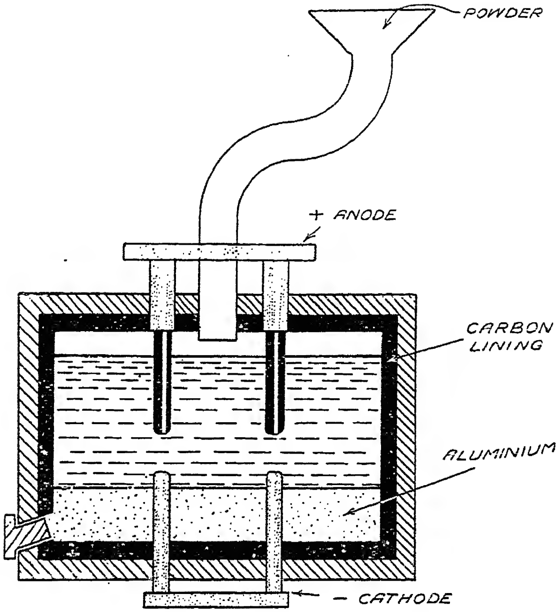


Fig. 25.—ALUMINIUM ELECTRIC FURNACE.

Defects in Hot Working

The most common defect likely to occur in the rolling mill is a sliver. This is a small piece of metal that becomes loose and is rolled into the surface. It often results from rolling out a scab.

Segregation

Steel is a mixture of several elements and compounds. It may also contain appreciable amounts of foreign matter. Some of the compounds have solidification points differing from the bulk of the metal and tend to concentrate on the upper part of the ingot, or the portion last to solidify. Segregation is this rejection and concentration of impurities.

ALUMINIUM

Aluminium is believed to be the third in order of abundance of all the elements, and is the most prevalent of all the metals. Most of it is, however, in a complex form which cannot, at present, be used profitably for production purposes. Bauxite and cryolite are the only important ores in use for the manufacture of aluminium ; bauxite, of which there are large deposits in Ireland, being in more general use.

Production of Aluminium

Bauxite has to be purified before aluminium can be manufactured. Purification is carried out with caustic soda solution under pressure.

This dissolves the aluminium oxide, leaving the impurities undissolved. The solution is then filtered and carbon dioxide used, which precipitates a fine white powder. The next operation is in an electric furnace for which special electrodes are necessary. The positives or anodes are carbon blocks and the negatives or cathodes are cast iron.

The white powder is delivered by pipes to the electric furnace, which is being operated at 5·5 volts. The furnace consists of a cast iron case packed with hard carbon. The gases which are produced escape through the vent pipe, which may also deliver the white powder. The heat generated by the electric current melts the ore and the oxygen combines with the carbon of the anode, forming carbon monoxide. The liberated aluminium sinks through the molten mass, the furnaces being tapped twice a week. The aluminium is carried by a conveyor to the refining furnace as quickly as possible, as the molten metal is rapidly oxidised by the air. The furnace is kept heated, so that any heavy impurities sink to the bottom of the pan.

The oxide is then skimmed off the surface of the metal, and the aluminium run into moulds.

Properties of Aluminium

The metal is silvery white in colour and has a specific gravity of 2·67 and melts at 1,200° F. It is the lightest of all useful metals except magnesium. It is soft, ductile, malleable, and in a pure state, offers a marked resistance to corrosion. Tenacity is about 7 tons per square inch. It can be worked by any of the common processes, such as rolling, spinning, stamping, drawing, tapping, forging, extruding, and machining. It can be electrically welded, but soldering is very difficult. The fact that pure aluminium is soft and of low tensile strength makes it unsuitable for many purposes, but it alloys readily with copper, manganese, magnesium, nickel, and silicon, and forms many useful alloys.

ALLOYS OF ALUMINIUM

Duralumin

This important aircraft alloy is composed of an aluminium base with approximately 4 per cent. of copper, or 0·05 per cent. manganese and 0·05 per cent of magnesium. A little silicon is also present as an impurity. The tensile strength is about 28 tons per square inch, and it has a specific gravity of 2·85. It has the property of age-hardening during the period of three to four days, after suitable heat treatment. It offers marked resistance to corrosion when in the fully age-hardened condition, and this useful characteristic can be intensified by a process known as "Anodising." The metal thus treated also has a marked resistance to the action of sea water and corrosive condition, provided the metal is not surface-damaged in any way.

Alpax

This is an aluminium silicon alloy containing 10–14 per cent. silicon, the remainder being aluminium. This alloy is used only for castings.

Alclad

This is an aluminium-coated duralumin sheet and must be uniformly covered on each side. The tensile strength is 24 tons per square inch and it is used for structural aircraft work.

Aluminium Base Alloys

The following table shows the composition and use of certain aluminium base alloys.

Copper per cent.		Manganese per cent.		Magnesium per cent.		Zinc per cent.		Nickel per cent.		Heat Treatments.	Remarks.
Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.		
3·5	4·5	0·4	0·7	0·4	0·7	—	—	—	—	Anneal 350°–420° C. Normalise 480°±10° C.	Wrought Aluminium Alloy bar. (Dural)
2·5	3·0	—	—	—	—	12·5	14·5	—	—		Alloy sheet (Dural)
3·5	4·5	—	—	1·2	1·7	—	—	1·8	2·3		Castings. "Y" Alloy
3·5	4·5	—	—	1·2	1·7	—	—	1·8	2·3	Anneal 360°–420° C. Normalise 490°-520°C.	Castings. "Y" Alloy Bar.

COPPER AND ITS ALLOYS

Most of the copper of commerce is extracted from sulphuretted ores, *i.e.*, iron sulphides of copper. This is a most complicated process, because the sulphides cannot be reduced by heating with carbon, owing to the iron content.

Method of Extraction from Ore

A typical procedure is first to crush the ore and then eliminate the silica and a great deal of the iron by oil flotation. The results of this operation are then roasted to remove other impurities. They are then smelted in a long and rather narrow furnace with a concave floor, together with silicious flux. It is heated by a flame from coal, the heat being reflected down upon the charge from the roof. Some of the sulphur is burned and part of the iron is converted into iron oxide ; this with the silicon forms a slag. The result is a heavy liquid called " copper matte," or " coarse metal."

The matte is again smelted in a blast furnace, similar to that used for making cast iron. The results of this are called various names depending upon the iron content. If " blue metal " or " pimple metal," it is then resmelted until the results are approximately 75 per cent. copper, when it is known as " fine metal."

Blister Copper

The " fine metal " is tapped off into a converter similar to the one used in the Bessemer process. Silica is then added and hot air is blown on to the molten mass. This forms copper and sulphur dioxide. As the copper cools, the sulphur dioxide is given off, leaving the copper covered with blisters, and is consequently known as " blister copper." It is approximately 95 per cent. pure metal.

Electrolytic Copper for Aircraft Work

For aircraft work the " blister copper " is purified by electrolysis. The blister copper is made the anode, the cathode being thin sheets of pure copper. The liquid is copper sulphate with about 12–15 per cent. of sulphuric acid and is maintained at a temperature of 120° F. The pure copper is deposited on the cathode, while the impurities collect at the bottom of the tank.

Alloys of Copper

Copper is used as the base of many alloys, the main ingredients being zinc, tin, iron and aluminium. Definite names have been given to these alloys. The two main classes are termed brasses and bronzes, the former being mainly zinc and copper, the latter tin and copper. They are manufactured by melting the copper, and, after skimming, adding the necessary percentage of alloying elements after they have been preheated.

The following are a few of the alloys :—

Bell metal	80% copper, 20% tin.
Brass	70–80% copper, 30–20% zinc.
Bronze	80–90% copper, 20–10% tin.
Delta metal	55–60% copper, 41–38% zinc, 4–2% iron.
German silver	60% copper, 20% nickel, 20% zinc.
Monel metal	27% copper, 68% nickel, 2–3% iron, manganese, etc., traces.
Phosphor bronze	99·5% bronze, 0·5% phosphor.
Constanton	60% copper, 40% nickel.
Manganin	81% copper, 17% manganese, 2% nickel.
Aluminium bronze	88% copper, 8% aluminium, 4% manganese and iron.
Gun metal	90% copper, 8% tin, 2% zinc.
Naval brass	59% copper, 38·5% zinc, 1·5% tin, 0·5% iron, 0·5% lead.

GENERAL SURVEY OF AIRCRAFT RADIO COMMUNICATION

By J. M. Furnival

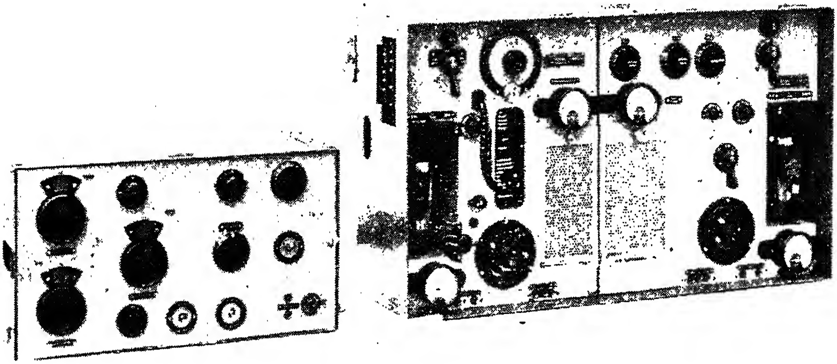


Fig. 1.—Marconi type A.D. 57/5872 short- and medium-wave aircraft transmitting and receiving equipment designed for Empire air route communications.

IT is possible to-day to convey intelligence by wireless from one point to another in one of several different ways. The most usual form is the transmission of telegraph messages, which can be sent in the Morse code by hand operation or by the automatic high speed system such as is used by the high-power telegraph services of the world.

As the automatic system—by means of which traffic may be sent at speeds of 400 words a minute or more—is too elaborate in equipment for use on present day aircraft it is necessary to limit the speed of sending to that which can be effected by the operator by hand key, which averages about 20 words per minute. The maximum amount of intelligence is, however, compressed into the message by the use of abbreviated codes.

Wireless Telephony for Flight Control

Some time prior to the Great War experiments had been made in speaking over the ether. The need for some direct means of communication between the leader of a formation and the members of his flight led to the war-time development from these early experiments of the aircraft wireless telephone for use by the Royal Air Force. This system of flight control by wireless telephony has nowadays become highly developed and is finding favour in many countries.

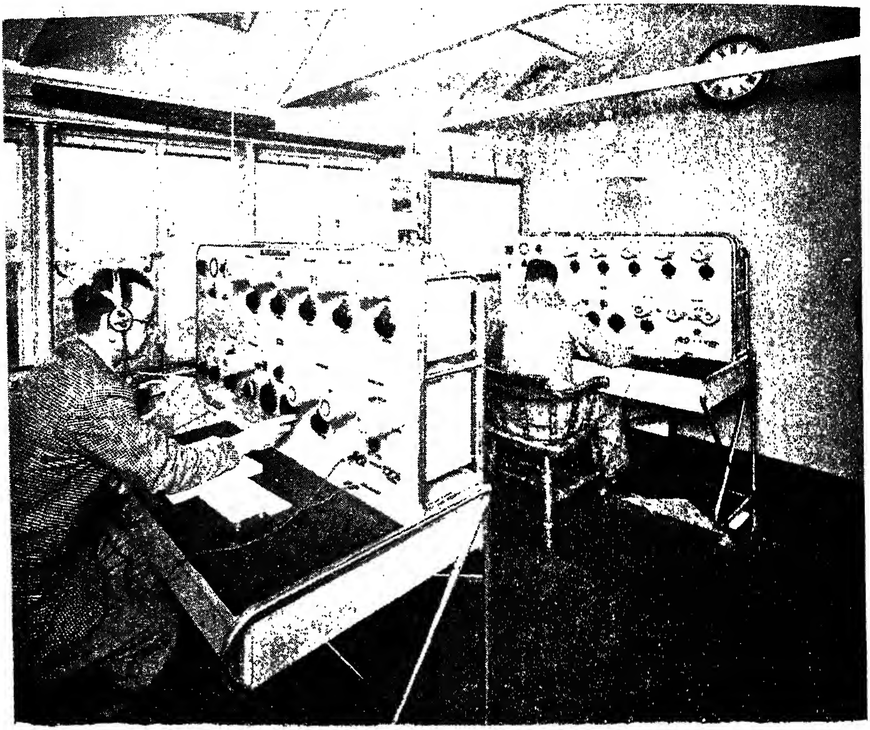


Fig. 2.—TWO MARCONI-ADCOCK D.F.G. 10 DIRECTION FINDERS WORKING OFF A COMMON AERIAL SYSTEM.

Facsimile Transmission

Yet another method of conveying intelligence is by the transmission of pictures and line drawings. A fairly compact form of apparatus has been devised whereby writing or sketches can be transmitted from air to ground or *vice versâ*.

Television

Finally, there is television. What service television can render to aviation has yet to be ascertained, but scientific and technical experts are already engaged on examining this problem.

Electro-Magnetic Wave Propagation

To appreciate the application of wireless to aircraft communication it is necessary to have some understanding of the characteristics of electro-magnetic wave propagation through the ether.

Whilst these waves travel through space with the speed of light, the length of the wave can be varied over a wide range by adjustment to the electrical capacity and inductance of the oscillatory circuit which includes the aerial from which the waves are radiated. By the choice

of suitable values of capacity and inductance, comprising the oscillatory circuit, the appropriate wavelength can be readily determined and calibrated.

Upon the wavelength used will depend the distance over which the waves will travel, the path they will take and the power necessary to produce them.

Wavelength Allocation

The wavelengths used in a normal broadcasting receiver, which range from 200–550 metres and from 1,000–2,000 metres, are those most suitable for reliable communication over medium distances. In the gap between 550 and 1,050 metres are to be found wavelengths which are allocated to mobile services.

Commercial Aviation 822–1050 metres

Six hundred and 800 metres are wavelengths allocated to ships and shore stations, whilst the majority of the aircraft communications of Europe, so far as commercial aviation is concerned, employ waves within the band 822–938 metres. Radio beacons for marine navigation occupy the band 950–1,050 metres.

Above these groups will be found the long wavelengths ranging from 3,000 to about 20,000 metres which are used by the high-power telegraph and telephone traffic stations of the world. Long-wave equipment is, generally speaking, too bulky for installation on aircraft.

Below the medium wavelengths are to be found the intermediate, short, and ultra-short waves, which have special application to aeronautical services.

For Military Work 50–200 metres

Intermediate waves between 50 and 200 metres are commonly used for commercial aviation in America and also by the military services for formation control by wireless telephony and the like.

Short Waves and their Possibilities

Below the intermediate wavelengths there lies the valuable band of short waves by the use of which it is possible to cover great distances over the earth's surface.

When such short waves are radiated from an aerial, propagation not only occurs over the earth's surface but at the same time a " sky ray " is radiated upwards and reflected back again to the surface of the earth from the " Heaviside " layer.

The distance over which it is possible to receive such waves will depend upon the wavelength used, time of day or night—longer waves by night and shorter by day—the season of the year and the region of the earth.

In addition to the advantage possessed by short wavelengths of

enabling great distances to be spanned with relatively small power, it has been found that short wavelengths are not so susceptible to atmospheric interference as is often the case with medium waves, particularly in tropical regions.

Why Combined Medium- and Short-wave Sets are used

Short-wave communication is, however, subject to fading at times and to a "skip" effect experienced when the down-coming ray arrives at the earth's surface beyond the range of the direct ray, so leaving a gap.

Because of these inconsistencies modern practice provides for the installation on large aircraft, such as service flying boats or commercial aeroplanes operating along the world's main air routes, of combined medium- and short-wave transmitting and receiving equipment by the use of which it is possible to obtain virtually 100 per cent. reliability.

The Question of Range

Although long-distance communication is not a primary requirement in connection with air route operation—about 500 miles being usually sufficient—very great distances have from time to time been covered.

The possibility of long-range short-wave communication from aircraft to ground was first observed during some early experiments conducted by collaboration between the Marconi Company and the Air Ministry many years ago. Wireless telephone messages transmitted to listening stations in this country having been picked up at Cairo. Later, when the first air route short-wave experiments were being conducted, communication was established from a flying boat over the North African route to the British Post Office station at Portishead near Bristol.

Upon another occasion it was found possible in the early morning to exchange greetings between New York and an aeroplane when flying over the Persian Gulf *en route* to India.

The Ultra-short Wave Band

Below the short wave band there exist the ultra-short waves which have a valuable application to aircraft services for short-range operations, such as are required for giving guidance when landing in conditions of bad visibility.

Ultra-short wavelengths become very rapidly attenuated as they travel over the earth's surface, but they also follow an optical path, behaving somewhat as light rays in this respect, so that high flying permits of greater distances being covered.

Since ultra-short waves are generally free from interference from afar and are not subject to atmospheric disturbances their employment in connection with local aircraft communication is likely to increase in the future, particularly as it is possible easily to direct the radiation into the form of a beam which can be employed for guiding purposes.

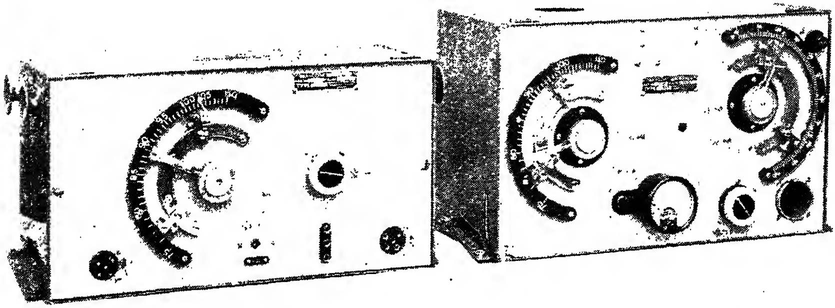


Fig. 3.—MARCONI TYPE A.D. 63 B. TRANSMITTER AND A.D. 64 B. RECEIVER DESIGNED FOR USE IN MODERN HIGH-SPEED AIRCRAFT.

On the other hand, these wavelengths are particularly susceptible to local "man-made static" and it becomes necessary to take strict precautions to ensure that the electrical and ignition systems on aeroplanes and engines are effectively shielded, otherwise a prohibitively high noise level would result.

Location of Sets

Modern sets of this type when installed in single-seater fighter aeroplanes are usually placed behind the pilot's seat and remotely controlled by electrical or mechanical means.

"Pre-set" Wavelengths

The pilot is usually provided with a choice of at least two "pre-set" wavelengths for use by day or by night, for working to the ground or to other aeroplanes or for the avoidance of interference which may sometimes be received from afar.

The microphone, specially designed and somewhat heavily damped so as to have anti-noise properties for the elimination of engine roar, will in most cases be incorporated in the oxygen mask required for high-altitude flying, and with this apparatus the pilot or observer will be able to keep in touch with the other aeroplanes in the formation and with the ground stations.

Ignition Interference

Ignition interference has long been the bugbear of the aircraft radio engineer, but steps have now been taken according to technique now well recognised whereby the fullest screening and bonding specifications of engines and airframe must be complied with where sensitive radio receivers are required to operate. The modern aero engine screening "harness" also cleans up the ignition wiring and installation, producing a better

engineering job tending towards reliability in all weathers and to ease of maintenance.

Navigating by Wireless

Hand in hand with the development of wireless for aircraft communication there has grown up an elaborate system of directional wireless for the navigating and guiding of aeroplanes out of sight of land.

Several different systems of directional wireless are in common use in connection with air navigation, but the principles involved are, broadly speaking, derived from the directional properties of a simple loop aerial which if rotated about its vertical axis in the path of the waves becomes non-receptive when precisely at right angles to the direction of their travel.

The Loop Aerial

Loop aerials of this type are now commonly fitted to large aeroplanes, the conductors being enclosed, excepting for a small insulating section, in a light metal tube of about 1 in. bore and formed into a circular loop about 12 or 18 in. in diameter. This loop is designed so as to be rotatable from the interior of the hull of the aeroplane by a hand wheel moving over a scale calibrated in degrees.

On some high-speed aeroplanes arrangements are made so that the loop may be retracted when not in actual use for the purpose of taking bearings. On smaller craft it is sometimes arranged to fix the loop permanently at right angles to the line of flight, the whole aeroplane being swung until the head of the aeroplane points to the station from which signals are being received. This latter form of directional guidance is termed " homing " and means have been devised so that the pilot can obtain a visual indication by a central reading meter installed on the dashboard. When he is on course the pointer of the meter remains in the central position. If he veers to the right or to the left the meter will show a corresponding deflection.

When using a rotating loop direction finder for the taking of bearings of stations " off course " it is necessary to observe the reading of the direction finder with reference to that of the magnetic compass. The bearings are then laid off on the navigator's chart, it being thus possible to plot the position of the aeroplane by taking bearings in fairly quick succession on two or more stations suitably situated.

Ground Organisation for Direction Finding

Although many of the large service and commercial types of aeroplanes have in late years been equipped with such direction-finding apparatus, the primary organisation for " D.F." is provided on the ground. The stations are situated at the main aerodrome and air route junctions or

occasionally to one side or another of a main route so that a service of bearings or fixes can be given on request.

The stations are provided and operated by the various administrations controlling the radio communication service in the territories over which the routes extend.

All that is required is for the aeroplane operators to call up and then transmit continuously for a brief period when one or more of the ground D.F. stations will take observations and the bearing or fix will in turn be passed back to the operator.

According to figures given in the Maybury Report, recently issued, no less than 32,000 directional bearings were given during the year 1935 by the British ground stations for which the Air Ministry are entirely responsible. It will thus be evident that the passage of messages involved in the operation of the ground D.F. service account for quite a large proportion of the total radio communication traffic.

Reflection of Wireless Waves

It is a characteristic of wave propagation that during the night and more particularly at sunset and sunrise the medium and to some extent long waves are subject to a considerable amount of reflection in a similar manner to that observed when short waves are employed.

Unless the direct ray along the earth's surface is much stronger than the reflected one, as would be the case at close ranges, the arrival of the reflected ray having undesirable characteristics upsets the operation of the instrument, causing wandering and obscuring of the minima.

The Marconi-Adcock System for Eliminating Reflected Rays

Methods have been devised, for example, by the Marconi-Adcock system, whereby the reflected ray can be substantially eliminated.

According to this system the normal loop aerials are substituted by four vertical conductors set at the corners of a square and connected through a radiogoniometer to the receiver by means of screened horizontal conductors which may be buried in the ground.

It will be appreciated that such methods are only applicable to ground stations and hence an extensive chain of them is being provided to serve the need of our main Empire routes so as to permit of the direction-finding service being rendered both by day and by night.

Experts are now engaged in applying the same methods to short-wave direction finders so that bearings can be taken over the much greater distances necessitated by the development of the Transatlantic air services of the future.

An Alternative System

An interesting alternative to the Adcock system is that of differentiating between the time of arrival of the direct and the reflected rays. That which follows the earth's surface will take the shorter path and will

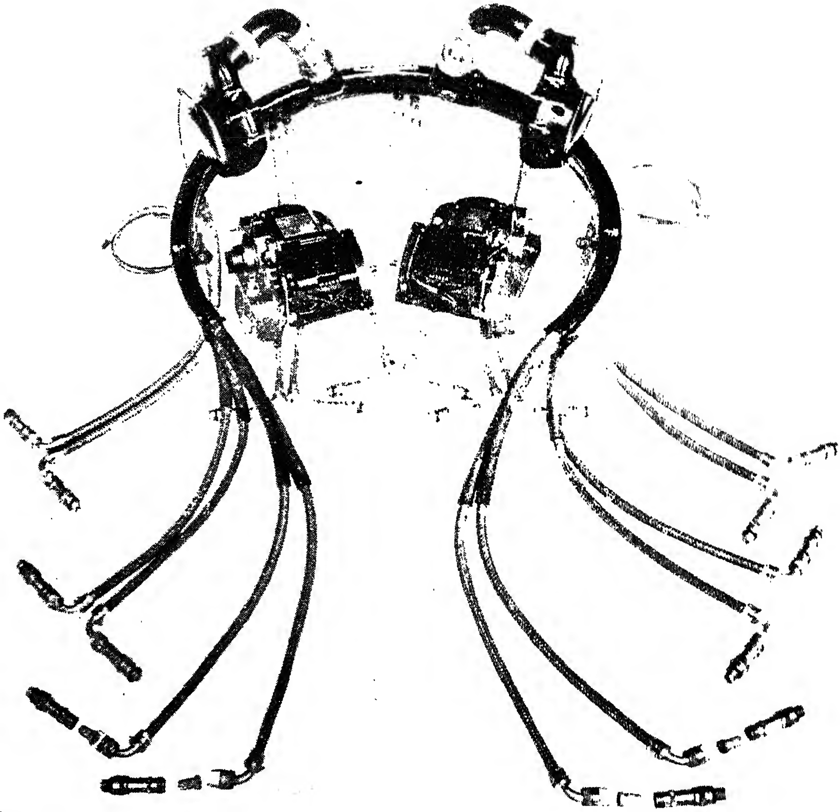


Fig. 4.—MARCONI SCREENING HARNESS TYPE 630 A. DESIGNED FOR A BRISTOL " PEGASUS " ENGINE.

arrive a fraction of a second before the down-coming ray from the sky. By the use of a cathode ray tube it is possible to discriminate between the two signals, and if the bearing is taken on the first arrival it will be free from night error.

Some of the more modern aircraft transmitters are designed so as to transmit a series of pulses to enable this form of error elimination to be employed by the ground direction-finding service.

American Practice

In America a somewhat different scheme of navigational guidance is employed. If a wireless transmitter is connected to a vertical loop aerial instead of to the usual open aerial and earth a directional field of radiation is produced. This field is likewise characterised by a sharply defined zero at right angles to the plane of the loop.

If two such loops are disposed at right angles to one another and arrangements made to transfer energy from one to the other in the rhythm of dots and dashes, an aeroplane fitted with a simple receiver will be able to steer a course along a path marked by these two over-lapping fields.

Should the aeroplane deviate to one side of the course or the other, dots and dashes will predominate. When on course the dots and dashes will merge together into one continuous tone or note.

Such a system will be subject to the same night errors which beset the loop direction-finding receiver, but investigation has shown that the substitution of four vertical aerials for the loop antenna has had the effect of substantially reducing the errors hitherto experienced.

Such directional transmitters have been developed and are extensively used in America where, under the name of "The Radio Range," they are employed to mark out the many internal and trans-continental air routes forming the great American network.

The "Radiophone" Service

As most of the available medium wavelengths are allotted to this "radio range" service, with which is combined weather broadcasting, the air to ground communications in America are worked on short and intermediate wavelengths by the highly developed "Radiophone" service.

By the extensive use of wireless telephony for weather information, etc., and by the simple A and N guiding system of the "radio range," the American authorities have found it possible to avoid the carriage of the professional wireless operator on their internal air routes.

Although on the European and Empire air routes radio communication and direction-finding services are at present closely interconnected, common equipment and operating staff being provided, it would appear that the tendency in the future will be towards the separation of the two systems so that wireless navigation can be carried on independently and as far as possible simultaneously with the communication service.

Modern Requirements Summarised

It will thus be seen that modern communication requirements call for the provision of equipment on the ground and in the air comprising short and/or medium wave transmitting and receiving apparatus together with direction-finding facilities embodying night error-free properties wherever possible. Supplementary ultra-short wave fog-landing equipment may also be fitted. In this connection it may be of interest to describe briefly the equipment now being provided for the new fleet of Empire and Transatlantic aircraft being placed into service by Imperial Airways Ltd.

Empire Flying Boats Equipment

On the Empire boats a combined medium- and short-wave transmitter is installed enabling waves between the limits of 17 and 75 metres or 600–1,100 metres to be radiated from either fixed or trailing aerial. The power for transmission is derived from two 1,000 watt generators mechanically driven from two of the four Bristol "Pegasus" engines. Power from these generators at about 25 volts is supplied through a control board to a specially designed motor generator set, the high and low tension output of which is connected to the anodes and filaments of the transmitting valves. The transmitter is designed in such a way that in the event of a failure of either short or medium wave portions the whole transmitter will not be put out of action.

The power of the transmitter is such that a range of 600 miles is normally to be obtained when transmitting continuous wave telegraphy over water, distances of 1,000 miles and upwards being bridged by the selection of a suitable short wave within the wide band provided.

Wireless telephony can be transmitted on medium wavelengths for local landing instructions, etc., and pulses on short wavelengths for the intended short wave direction-finding services of the future.

The Power Supply

In case of emergency it is possible to drive the motor generator by a small petrol engine through a special clutch or coupling. The engine can be instantaneously connected and started electrically. When it is necessary to do so, it is possible to use this combination for replenishing the main batteries of the aeroplane, the motor of the motor generator being converted to a dynamo for the purpose.

The Trailing Aerial

When in flight a trailing aerial may be used to extend the range of transmission to the maximum required. The aerial is lowered through a fairlead which is retracted into the hull of the boat before alighting on the water. When it is desired to transmit messages from the boat on the water the fixed aerial is employed, the height of which may be increased to the maximum permissible extent by the use of a telescopic mast.

The All-purpose Receiver

For the reception of messages and for direction-finding services on board the Empire boats an all-purpose short-wave, medium-wave, and direction-finding receiver is provided. This receiver works in conjunction with a dipole aerial for short-wave reception and a 19 in. rotatable and retractable loop for direction finding.

When this loop is in use the output from the receiver is taken to a switching unit by means of which three different methods of directional reception can be applied, namely, the usual minimum method, zero

sharpening being applied to facilitate the accurate measurement of the bearing, the equal signal system, in which an equal balance of signal on either side of a hand switch indicates the bearing, and the visual method by centre reading indicator on the pilot's dashboard.

This latter method is only suitable where bearings are taken on a station sending a continuous carrier such as a broadcasting transmitter.

Transatlantic Aircraft Equipment

On the aircraft destined for the Transatlantic service a somewhat more elaborate equipment is installed. Thus, in addition to the wave bands provided for the standard Empire service, an additional band covering 90–190 metres is provided to enable British aeroplanes to use the wavelengths allocated in America to aeronautical services. One of these wavelengths is 183 metres, which has been adopted by Pan-American Airways for much of their communication service.

On the Transatlantic aeroplanes an additional receiver is carried for direction finding, whilst on certain aeroplanes ultra-short wave fog-landing equipment is also installed.

By the use of such equipment working in conjunction with the highly organised ground station service comprising short- and medium-wave transmitting and D.F. receiving apparatus established at suitable points in Ireland, Newfoundland, Bermuda, Azores and at New York, it is anticipated that it will be possible to maintain the constant communication and direction-finding facilities required for the Transatlantic air services of the future.

A Vital Problem

One of the vital problems of the present day is the congestion of traffic through the ether, brought about by the general growth of air services and also by the increase of messages in connection with the control of flight under bad weather conditions. Consequently every care has to be exercised by the designers of aircraft apparatus so that as many channels as possible may be worked in any given wave band. This means the provision of transmitters capable of being set very accurately to the allotted wavelength. Arrangements must be made for the quick selection, if necessary by remote control, of any one of four or five pre-set wavelengths. Receivers must be correspondingly selective and easy of adjustment.

Details of ground equipment and aeroplane wireless equipment will be given in later articles.

CARBURATION

SECTION I—THE CLAUDEL-HOBSON AERO CARBURETTER

By E. W. KNOTT, M.I.A.E., M.S.A.E.

THE present-day carburetter is an instrument of high precision manufacture. It is whirled through the air at colossal speeds, catapulted violently and tilted to every conceivable position in the air. It is jolted and subjected to vibration and yet has to function perfectly.

Before dealing with the technical details of an aeroplane carburetter, it is opportune to describe some of the primary requirements.

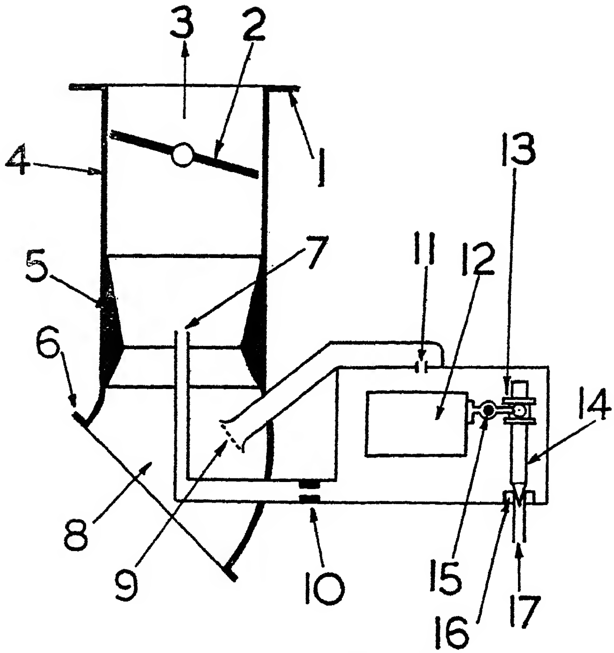
1. The mixture strength must not be affected by changes in speed of the aeroplane.
2. The engine must start up easily and, when warm, tick-over steadily.
3. The engine must accelerate instantly and unfailingly.
4. It must use the minimum amount of fuel consistent with safety, under all conditions of flight, including varying altitudes.
5. It must be capable of being manufactured in series with very close similarity in performance.

Fig. 1 shows a simple carburetter. It consists of a float chamber, which is a device for keeping the fuel from exceeding a predetermined height and which works in a similar fashion to an ordinary ball valve in a water cistern. Connected to the induction system is a pipe in which is a waisted restriction known as the choke tube and between the choke tube and the engine is a rotatable disc known as the throttle plate, by opening or closing which, control can be had of the amount of mixture passing to the engine, which mixture consists of air drawn from outside the carburetter and fuel fed into the choke tube from the float chamber. Various means are provided for correctly proportioning the fuel and air under all conditions.

THE CLAUDEL-HOBSON CARBURETTER

These carburetters are designed to operate on high efficiency engines. They are very carefully pressure balanced and have a mixture control for altitudes up to at least 30,000 feet, although this percentage of control can be cut down if necessary. This demand for great range of control at altitude calls for extreme care in design to ensure smooth and progressive weakening of the mixture strength and it is essential that the amount of control at any height is not altered with varying throttle openings.

Because of the amount of altitude control available, it is imperative



1. Induction Flange.
2. Throttle.
3. Direction of Mixture to Engine.
4. Throttle Bore.
5. Choke.
6. Air Intake Flange.
7. Free Discharge Tube.
8. Air Intake.
9. Pressure Balance Tube.
10. Main Jet.
11. Air Vent to Float Chamber.
12. Float.
13. Needle Collar.
14. Needle.
15. Float Spindle.
16. Needle Seating.
17. Fuel Connection.

Fig. 1.—A SIMPLE CARBURETTER.

that there is some form of interlocking gear which will close the mixture valve if the throttle is closed, as if a pilot descends to earth with a very weak mixture, there is the ever-present risk of the engine stopping, which may easily cause a bad landing. This interlocking gear was formerly fitted to the carburetter, but as the point at which it was desirable for the throttle to start to close the valve varied in different aeroplanes, it is now incorporated in a pilot's control-lever box specially designed for a particular combination of engine and aeroplane.

Proportioning of the mixture strength is by means of a diffuser using a progressively emptying well and the use of a power jet provides maximum power at full throttle, yet enables extremely economical mixtures to be used throughout the range of cruising speed. The butterfly throttle is novel in principle and instead of being merely a means of controlling the quantity of mixture passing to the engine, is definitely part of the slow running system.

The use of very weak mixtures for cruising makes an engine difficult to accelerate and this in combination with a supercharger with its relatively large capacity and wall area makes it necessary to give a temporary injection of fuel into the induction system each time the throttle is opened. For unsupercharged engines, a simple piston type pump or squirt operated by the throttle lever is satisfactory, but with supercharged engines this is not sufficient, for the discharged fuel almost wholly deposits itself on

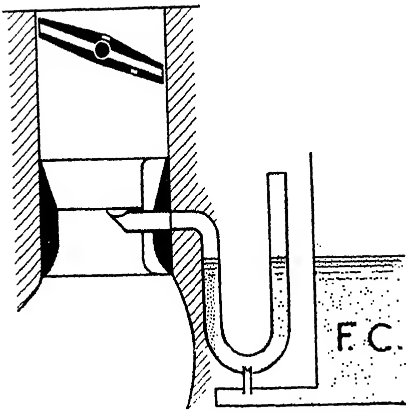


Fig. 2.—SHOWING CONDITIONS WHEN THE THROTTLE IS CLOSED.

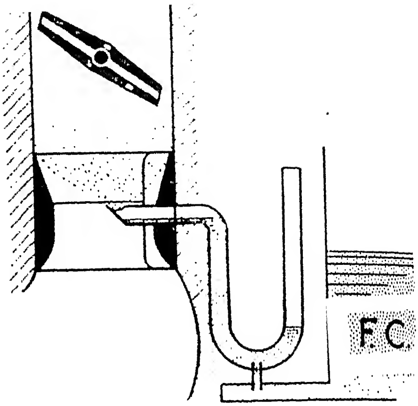


Fig. 3.—SHOWING CONDITIONS WHEN THE THROTTLE IS PARTLY OPENED.

the walls of the blower and induction pipes and the cylinders do not get the necessary temporary enrichment as the throttle is opened.

Delayed Action Accelerating Pump

A form of pump to overcome the above deficiency has now been incorporated. The pump has two pistons, one mechanically operated when the throttle is opened and another operated by a spring which is compressed when the first piston is moved. Its action is as follows. Movement of the throttle causes the first piston to forcibly eject a mass discharge of fuel, which thoroughly wets the walls of the blower and induction system. It is followed without any pause by a sustained discharge lasting for 2 to 5 seconds, which assists the engine to accelerate through the speed range where temporary weakness would cause the engine to backfire badly or even stop altogether.

Diagrammatic Description

In describing the system of working of the Claudel-Hobson carburetter, special emphasis is laid on the construction and functioning of the diffuser. The latter is that part of the carburetter that correctly proportions the fuel and air passing to the engine and its action is as follows. If reference is made to Fig. 2, a U tube will be seen fed *viâ* a restriction from a float chamber. With the throttle closed, the pressure on the exit side of the U tube is at atmosphere and being balanced by the air pressure on the other limb of the U tube, the fuel stands at the same height in both limbs. Fig. 3 shows the throttle partly open, with air passing through the choke tube. As a result of this, the pressure in the choke tube drops below atmospheric, while the free end remains at atmospheric pressure; therefore the fuel will be driven out into the choke tube, this operation

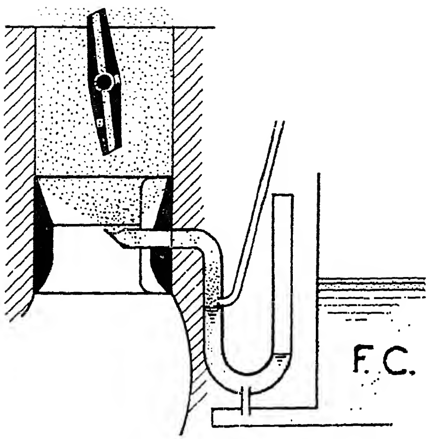


Fig. 4.—DIFFUSER AIR BEING DRAWN IN AND FORMING AN EMULSION.

This passes into the choke and mixes with the main air supply.

by pressure difference being commonly called " suction." As constructed in Fig. 3 the fuel would enter the choke tube entirely unatomised and one purpose of the diffuser is to break up the fuel before it enters the air stream.

In Fig. 4 a pipe is shown which allows air to enter the exit limb of the U tube below fuel level, air being driven in by atmospheric pressure where it mixes with the fuel to form an emulsion.

In actual practice a diffuser of U pattern is not used, the construction being as in Fig. 5, the two limbs of the U tube being in effect one inside the other. In some models the slow running jet is mounted concentrically in the diffuser, whilst in others it is separate, but in either method the action of the slow running system is the same. In Fig. 5, the carburetter is shown in the slow running or idling condition. The throttle is only very slightly open and the air speed through the choke tube is so slow that the diffuser is inoperative. Fuel passes through the slow running jet tube, being mixed with air on its way, which air enters by holes in the side of the slow running tubes. From there it passes to a small cavity having two discharge holes, one opposite the edge of the throttle and the other just below.

The throttle is of special construction, having a hole through it known as the transverse passage, which has two small holes drilled into it, a discharge hole in the centre on the engine side and an air entry hole on the opposite side. With the engine running and the throttle in the slow running position, fuel is discharged from the upper discharge hole, some of it passing across the transverse passage and issuing on the other side of the throttle, the remainder entering the air stream from the small hole in the centre of the throttle and on the side of the throttle nearest to the discharge hole. Thus a perfectly distributed mixture is obtained over the whole of the area of the throttle bore, better slow running and absence of " loading-up " through condensed fuel being obtained.

As the throttle is opened up, the transverse passage comes opposite the second discharge hole. Up to the present, air has been entering this hole, helping to dilute the slow running mixture, the *quantity* of mixture being controlled by an adjustable screw. In some cases, the screw is used to vary the size of an air leak into the slow running system and is

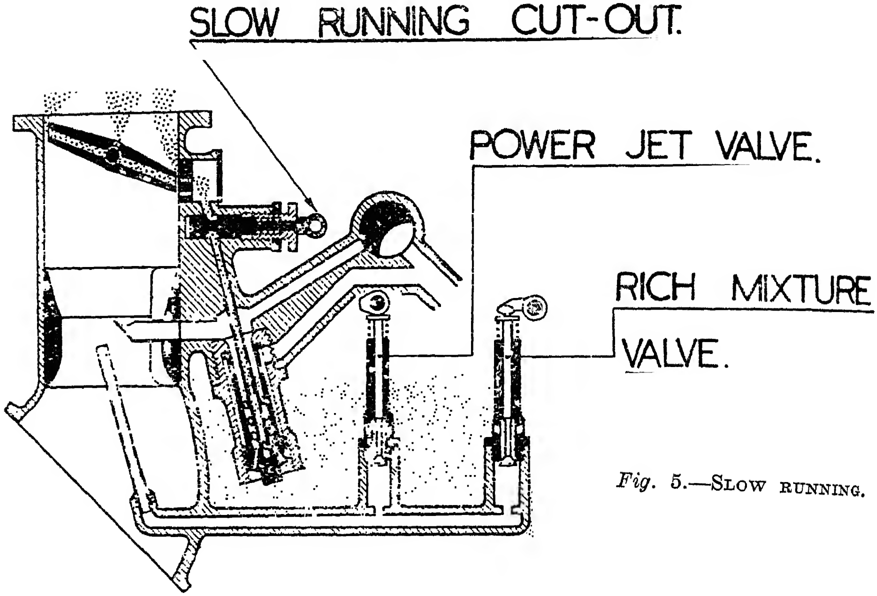


Fig. 5.—SLOW RUNNING.

then known as a *quality* adjustment. Suction is now put on the second hole as well as the first, thereby giving the extra fuel necessitated by the larger throttle opening. As the throttle is opened even further, the drop in pressure in the choke tube becomes sufficient to draw fuel from the diffuser and the two systems if properly adjusted merge smoothly into one another, the slow running discharge fading out as the diffuser discharge increases. This is the most critical part of a carburetter's performance and also the most difficult to adjust, and the Hobson form of throttle greatly simplifies this adjustment.

The Main Jet

At the bottom of the diffuser is the main jet, which is interchangeable, and a size is chosen which gives a low fuel consumption through the cruising range which may be anything between a half and three-quarters full throttle opening, depending on the type and size of engine relative to the size of aeroplane. Fig. 6 shows a small throttle opening, but sufficient to draw fuel from the diffuser, and at this opening the fuel level in the diffuser will have dropped. This has uncovered some of the holes in the side and air is entering and mixing with the fuel. Fig. 6 shows the throttle approaching full power conditions near ground level. In view of the extra power given and the higher temperatures which are reached by the engine, the mixture strength suitable for economical cruising speeds is too weak and extra fuel must be given to prevent detonation and to internally cool the engine.

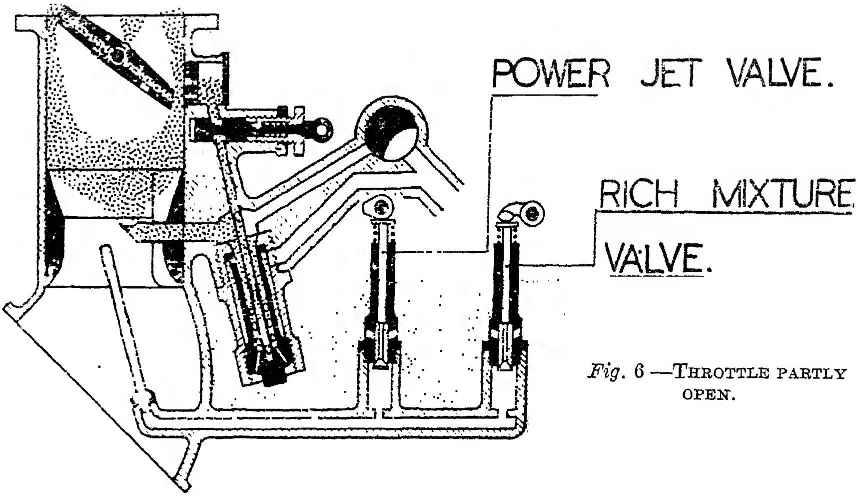


Fig. 6 —THROTTLE PARTLY OPEN.

The Power Jet

The extra fuel for full power conditions is obtained by opening a valve, called the power jet valve, in the float chamber which allows fuel to flow through another jet called the power jet. This jet is also interchangeable and a size is chosen which keeps the engine free from detonation and at safe temperatures. In carburetters for *unsupercharged* engines, it is permissible to time this power valve opening from the throttle, a cam or similar device on the throttle spindle shaft being used to open the valve, so that at a predetermined angular opening of the throttle (corresponding to a certain power output) the power jet always comes into action. This is known as the power jet timing and is usually specified as so many degrees from the full open throttle position.

On *supercharged* engines, however, for reasons which will be gone into later, timing the power jet off the throttle spindle is not satisfactory and other methods have to be employed. Fig. 7 shows the power jet valve open and the level in the diffuser will have dropped considerably, more air holes being uncovered. The size, number and position of the holes in the side of the diffuser are varied in order to obtain the required mixture strength at any throttle opening.

Correction

If a plain jet is subjected to suction such as is obtained in a carburetter, its fuel flow in relation to air flow does not remain constant, but becomes increasingly richer as the suction increases, far too rich for practical purposes. Some method must be used to counteract this tendency and is known as the means of correction and is the subject matter of hundreds

of patents. In the Claudel-Hobson carburetter this correction is obtained by their diffuser system.

The control of fuel flow by means of tapered needles moving up and down in an orifice has been and still is used in some makes of carburetters, but suffers from the following defects. The needle must be guided so that it always remains exactly central in the orifice or the discharge characteristic varies. Vibration causes rapid wear in the guides and the accuracy of measuring of such a system soon suffers. Particularly is this evident when the needles are operated by the expansion and contraction of barometric capsules, as owing to the small power they can exert, the needles require a minimum of friction which means very free guides, which freedom of fit accelerates the wear from vibration. Extremely slight differences in the shape of a needle give widely varying changes in mixture strength for the following reasons. An engine requires a proportion by *weight* of fuel to air of from 1 to 10 for best power, to 1 to 16 for best economy. The figures are subject to some fluctuation according to the make and type of engine and its running conditions. As it is difficult to visualise the weight of air, the fact that a 1 to 16 mixture by weight represents 1 two-gallon can of fuel to 10,200 cans of air will convey a better conception of the proportions. With such proportions it will be seen that a small percentage error measurement of fuel causes a vastly greater change in mixture strength than a small error in the measurement of the air and a fuel jet of fixed size and an air correction device are the more reliable. This has been confirmed in U.S.A. and needle controlled fuel measuring devices have been the subject of much criticism there and have finally been entirely dropped by one of the best-known aircraft carburetter manufacturers.

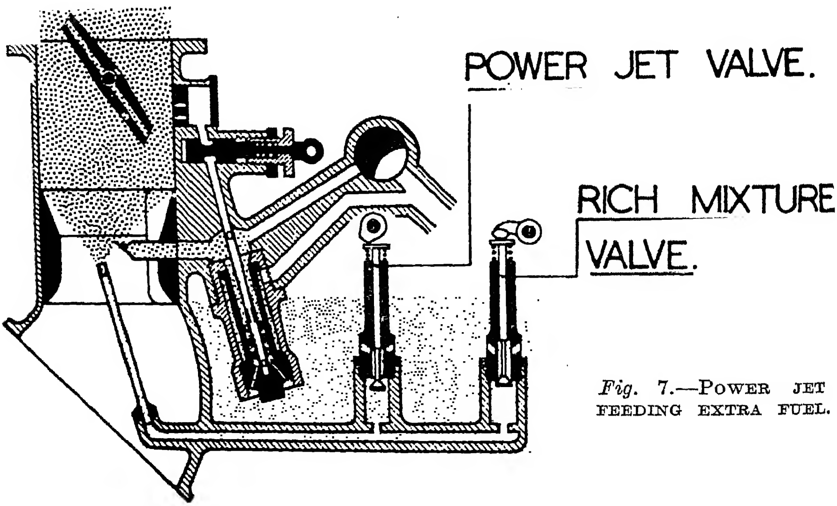


Fig. 7.—POWER JET FEEDING EXTRA FUEL.

Mixture Control

If a carburetter is adjusted to give correct mixture strength on the ground, the mixture will be too rich at altitude, due to the decrease in oxygen, and the higher the engine goes the greater becomes this over-richness, which causes loss of power and waste of fuel. Some means, therefore, must be provided to bring the mixture strength back to normal and is known as the mixture control device. The design is by no means easy, for the degree of control must vary solely with height for any given setting and must not change with variations in throttle opening or forward speed of the aeroplane. The carburetter has a mixture control-lever on it which can be controlled from the pilot's seat and by this means the mixture strength can be altered at will by the pilot, depending on the altitude at which he is flying. The correct use of a hand-operated mixture control requires a combination of skill and conscientiousness on the part of the pilot, as he can either waste fuel and thereby reduce the range of the aeroplane, or damage his engine by running on too weak a mixture. As much as 50 per cent. differences in fuel consumption are often recorded when the same aeroplane is flown by different pilots under identical conditions and while on civil types a certain amount of attention can be given to this subject, where military types are executing aerobatics, or in wartime, it is impossible for the pilot to pay attention to his mixture strength. Means have now been provided whereby the mixture strength is automatically corrected for any altitude, the mixture lever on the carburetter being moved by a specially constructed instrument and not by the pilot.

Fig. 8 shows the mixture control-valve on the Claudel-Hobson carburetter. A cone-shaped cock with openings in it has been turned, admitting air between the diffuser and the choke tube. This reduces the suction on the jet, thereby weakening the mixture, the larger the cock opening the greater being the reduction in fuel flow. In order that the air flow through the mixture valve shall not be affected by the speed of the aeroplane, etc., the air is taken from the pressure balance tube in the carburetter intake, suitable means being taken to prevent snow or rain from entering.

Rich Mixture for Take-off

Where the degree of supercharging is sufficient to make it unsafe to open fully the throttle at ground level when taking-off and the maximum ground level throttle opening is specified by the engine makers, it is permissible to slightly exceed this opening for a very short period, say 1 to 3 minutes, provided additional fuel over and above that added by the power jet is given. It has been found that an addition of 10–15 per cent. has in some cases enabled as much as 17 or 18 per cent. increase in power to be obtained, a useful addition when taking an aeroplane off the ground. This fuel is obtained from the float chamber by opening a

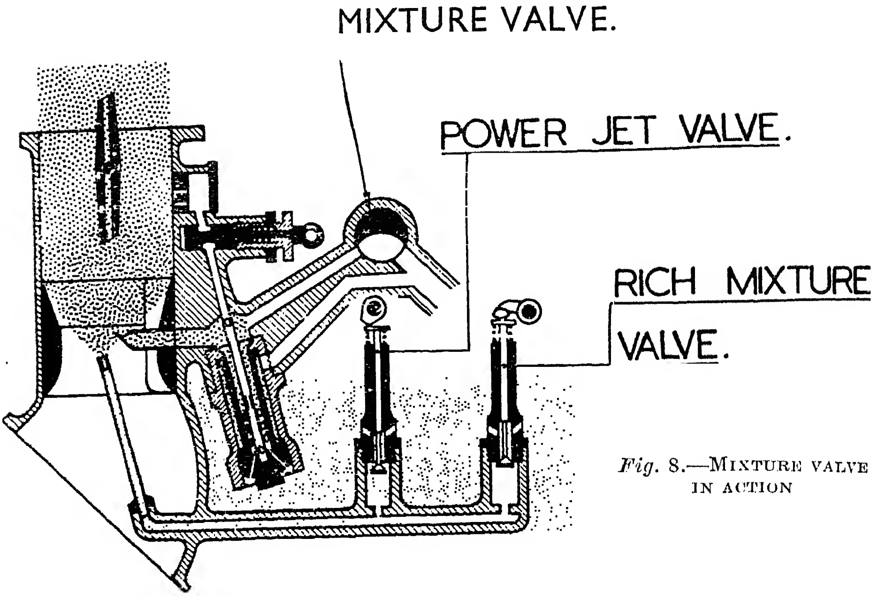


Fig. 8.—MIXTURE VALVE IN ACTION

valve similar in principle to the power jet valve and is known as the enrichment valve. Its action can be seen in Fig. 9.

The general principles described above apply to all Claudel-Hobson carburetters and once grasped will enable any type or size of this carburetter to be understood.

Float Mechanism

Air Ministry regulations regarding float mechanism call for skill and experience in design. The float chamber must pass a big margin over and above the maximum that the engine will ever require at a minimum head of 10 in. and withstand a head of 12 ft. (approximately 4 lbs. per square inch pressure) without flooding. The carburetter must also be capable of being tilted in any direction to an angle of 15 degrees without flooding at the maximum test pressure. Now that carburetters are largely fed direct by fuel pumps, a concession in such cases regarding minimum pressures has been made, the limits being the minimum pump pressure, usually equal to 18 in. head. Float needles and seats have to be made of special material to withstand the wear and tear due to vibration and the floats themselves built up from layers of cork given many coats of a special varnish proof against the action of warm fuels of all kinds.

Corrosion

This can be of serious consequences and is accentuated if water is present in the float chamber. Where the removal of the jets does not

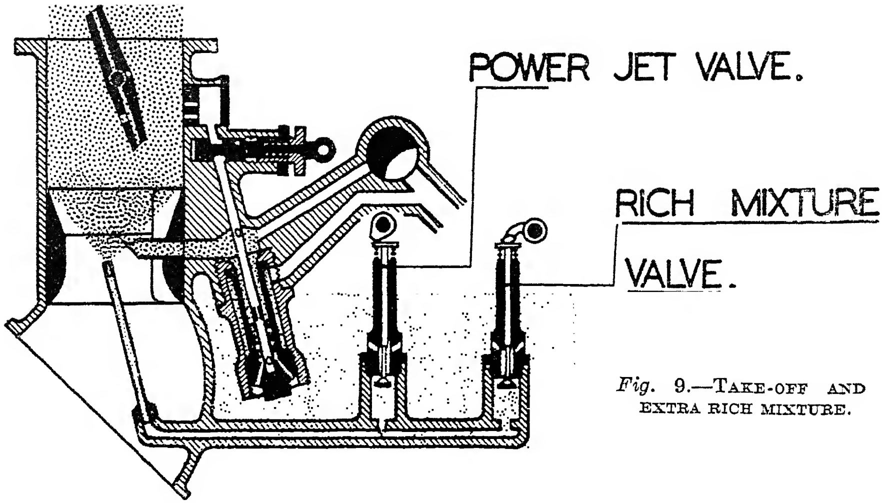


Fig. 9.—TAKE-OFF AND EXTRA RICH MIXTURE.

allow this to be removed, drain plugs are fitted and the float chamber should be emptied after every few hours' flight and without exception after flying through snow, hail or rain. The choice of the materials used is also important as electrolytic action will take place, this being greatly accentuated when certain types of jointing material are used. Its presence is indicated by the growth of a white or yellowish-white crystalline substance and in some cases a jelly. This must be particularly watched for on seaplanes and on aeroplanes stored or in use near the sea. Magnesium is particularly treacherous in the presence of leaded fuels where water is present and it may not be used for carburetter float chambers.

Carburetter Air Intakes

The design of the air intake requires great care and once fixed by the engine maker must on no account be altered or the engine performance may be seriously affected. Air intakes are often constructed with a flap under the control of the pilot whereby either hot or cold air can be used. In some instances the flap is operated by the throttle lever, so that hot air is given during slow running and through the cruising range, whilst at full throttle cold air is given so as to obtain maximum power. With the latter arrangement, however, the pilot should have an overriding device so that if flying through snow or cold rain, some hot air can be given at full throttle, to prevent freezing in the induction system. A badly-designed air intake can cause the air passing the carburetter pressure balance orifice to whirl or alter its direction so badly with different throttle openings or forward speeds of the aeroplane that

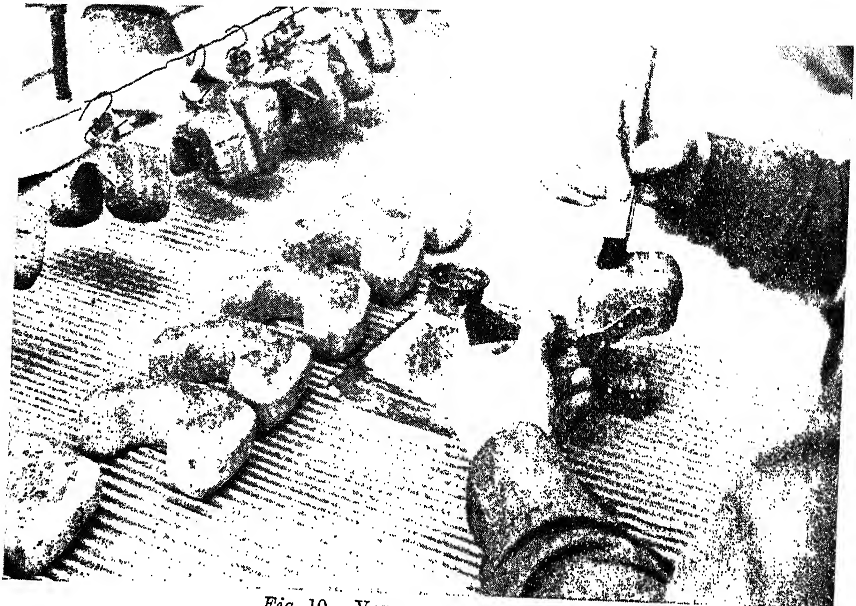


Fig. 10.—VARNISHING FLOATS. [*Claudel-Hobson.*

They are given fifteen coats of special varnish and it must be done in a warm, dry atmosphere.

carburation is upset. Thin sheet metal vanes following the general air path into the carburetter are of great help. They should be parallel to one another and may be in layers or of a pattern similar to the divisions in an egg box and are known as straightener vanes. See Fig. 11.

Slow Running Cut-outs

All modern aeroplane carburetters for supercharged or high compression engines are fitted with these for the following reasons. After a prolonged spell of hard work, frequently some part inside the cylinder heads becomes incandescent, *i.e.*, sufficiently hot to fire the incoming charge without the aid of the magnetos and sparking plugs. These parts may include exhaust valves, carbon deposit and plug points. The result is that although the pilot closes his throttle to the "tick-over" position and switches off the engine continues to run on the mixture normally supplied by the slow running jet, but fired by the incandescent point in the cylinder head. With land types, which to-day, if of any size, are invariably fitted with wheel brakes under the control of the pilot, stoppage of the aeroplane is simple. With flying boats, seaplanes, etc., which have to alight on water, such means are not available, and many instances have occurred where mooring buoys have been overshot and the plane has drifted on until a serious collision brings it to a standstill, the pilot being helpless to avert

such a collision. By arranging to cut off all fuel supply to the slow running system, an engine running under such conditions can be instantly stopped, and such aeroplanes have in the cockpit a lever or other means which when operated by the pilot effectively cuts off the slow running fuel. See Fig. 5.

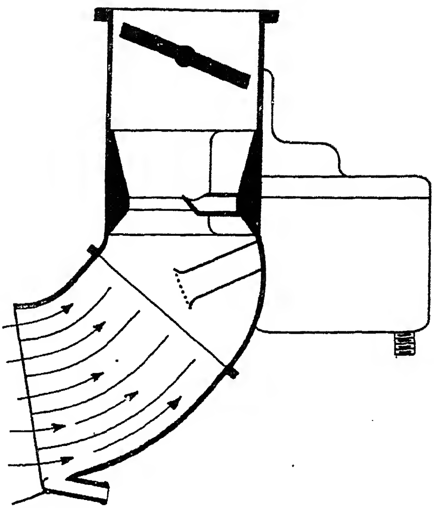


Fig. 11.—STRAIGHTENER VANES IN CARBURETTER AIR INTAKE.

These are to prevent carburation being spoilt by vortices near the pressure balance tube and choke.

Engines will frequently run quite steadily under conditions of auto- or self-ignition for some minutes, gradually getting more irregular as they cool down. Eventually the engine misfires, stops and then runs backwards for three or four turns. This sudden reversal can easily damage such parts as supercharger gearing, valve gear, etc., and owing to the reversal of the oil pumps, often fills the bottom cylinders of radial engines with a large quantity of oil, necessitating a thorough clean out.

MAINTENANCE

Aero carburetters are expensive instruments of high precision workmanship and must be handled with the greatest care.

Engines are often transported with the carburetter packed separately, the intake flange on the engine being blanked off with a plate. Before fitting the carburetter it should be inspected for dirt, loose plugs and similar fittings, and all parts drilled for wiring should be examined to see that they are securely wired. Loose or cracked wiring should be renewed.

If it is not known that the carburetter was thoroughly cleaned out after removal from the engine, the drain plugs and jets should be removed and thoroughly washed out with clean petrol, and the plugs, etc., wired after refitting.

The flange face should be lightly smeared with one of the well-known jointing compounds, and all fixing nuts carefully tightened a little at a time, in turn, to avoid straining the flanges, pen steel washers being fitted next to the carburetter body to prevent the metal being scored by the lock washers. The use of thick gasket material may cause bent or broken flanges and $\frac{1}{32}$ in. is the maximum thickness allowable.

Should the carburetter be unused for a lengthy period, it should be

stored in a dry place, and all plugs or screws fitted with fibre washers should be taken out of the carburetter, the fibre washers removed and the plugs replaced finger-tight. The fibre washers should be wrapped up and attached to the carburetter. Slacken the float spindle only.

To prevent the ingress of foreign matter, all orifices are to be blanked off. Male threads, such as on unions, are to have sheet copper or aluminium blanking discs held in place by the appropriate union nut, which is to be screwed hard home.

Tapped holes are to be blanked off by soft wooden taper plugs screwed well in, leaving sufficient protruding for extraction. These plugs must be screwed in, and on no account driven in.

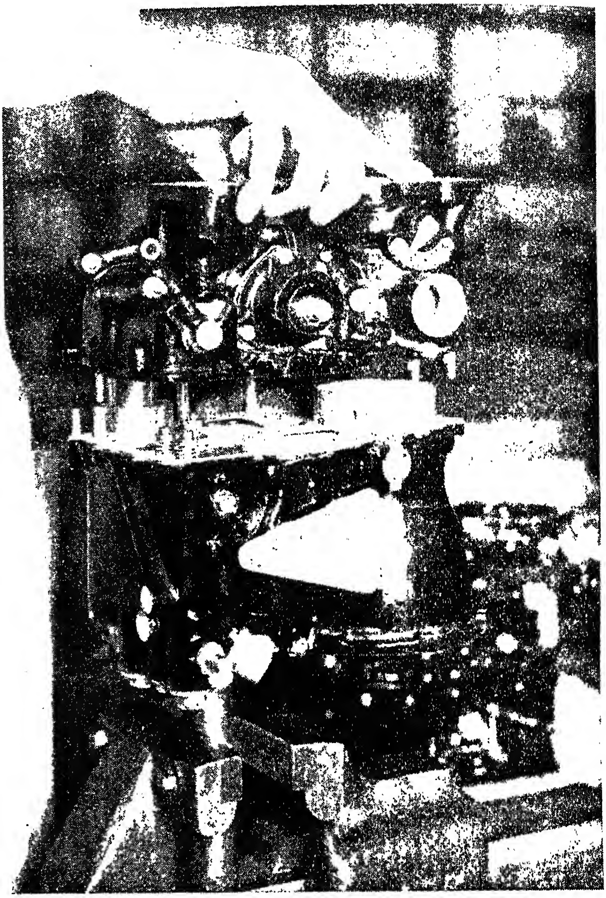


Fig. 12.—STRIPPING A CARBURETTER.

Remove a drain plug or jet and hold carburetter by means of a screwed plug held in a vice. Separate top and bottom half slowly and gently.

Other exposed orifices, such as air intakes and flanges, are best blanked by means of three-ply wood held in place by the most convenient means, such as existing studs or bolts. Moving parts such as throttle spindle bearings should be lubricated.

All steel parts such as nuts, etc., not enamelled or otherwise protected, are to be well coated with an approved rust preventative.

Jets

These should never in any circumstances have their bore altered by reaming, burring or soldering.

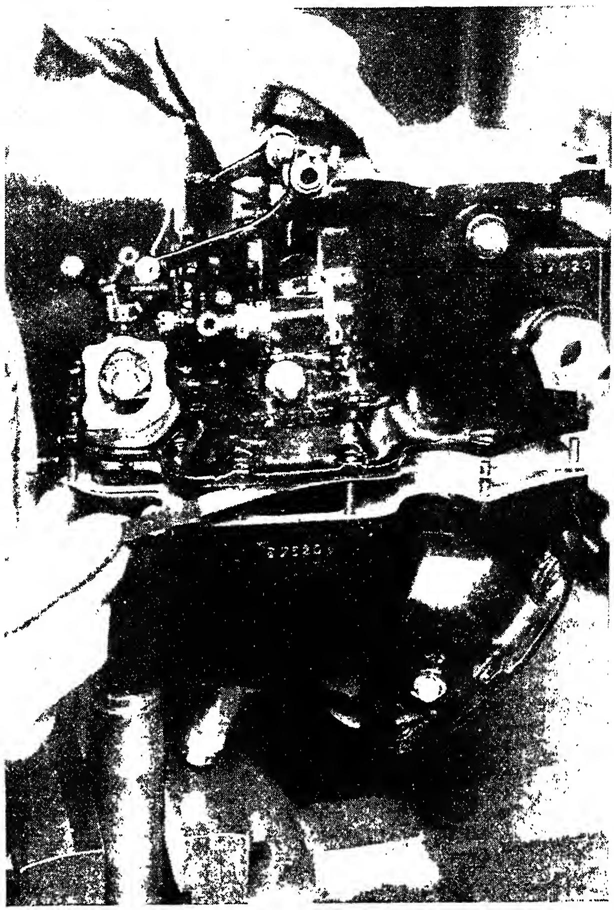


Fig. 13.—STRIPPING A CARBURETTER.

Separate the top and bottom halves slowly as some of the jointing material may stick to the top and some to the lower part. Use a pocket rule or penknife to slip the jointing over the studs without damage. Always use a new gasket whenever possible and tighten the nuts a little at a time and not each nut completely in turn.

Tampering with jet sizes in this manner, although often invisible to the eye, can cause large differences in fuel flow, and a new jet of the correct size should be fitted if any alteration is deemed necessary. The flow through the jet in cubic centimetres per minute, as found on a standardised flowmeter, is marked on the jet. Never use wire for cleaning a jet orifice; blow through it.

Care should be taken when screwing jets into the carburetter. Should a jet feel tight whilst being screwed in, or have a tendency to seize, the jet should on no account be forced into place, or serious damage to both jet and carburetter body may result. Remove the jet and look for the cause. Examine the threads in the body for swarf, or portions of thread torn from the jet through careless fitting, and jammed in the thread in the body. Excessive tightening of parts such as jets, etc., may permanently damage the threads in the body, and even stretch the threads of the jet "out of pitch," thereby causing difficulty both in screwing and unscrewing. Jets and similar parts which are obviously damaged in this way should be scrapped and replaced by new ones.

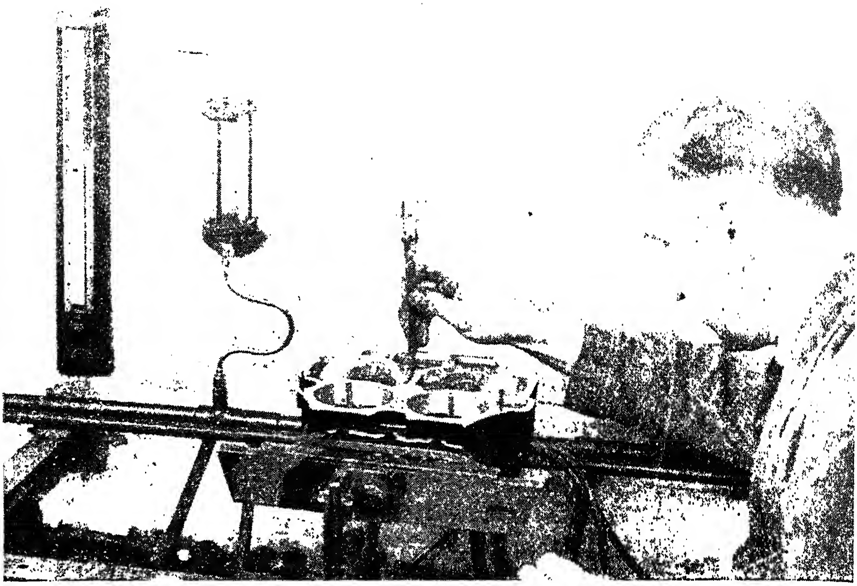


Fig. 14.—CHECKING FUEL LEVEL DURING MANUFACTURE.

Fuel is fed to the float chamber under the regulation pressure, which is recorded on a mercury U tube seen on the left. The height from the parting face is measured by a rule or slide gauge and must be within plus or minus one millimetre of the correct level. Only after long use should the level require altering.

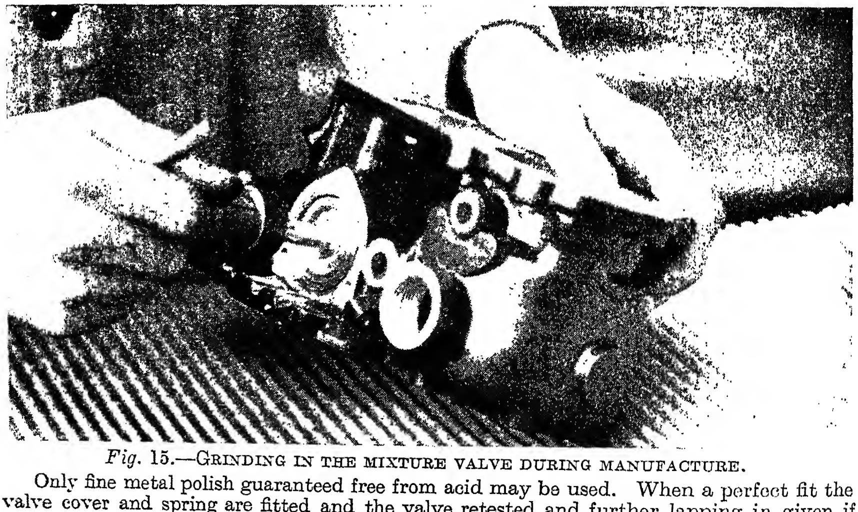


Fig. 15.—GRINDING IN THE MIXTURE VALVE DURING MANUFACTURE.

Only fine metal polish guaranteed free from acid may be used. When a perfect fit the valve cover and spring are fitted and the valve retested and further lapping in given if necessary. After long use or storage, this valve and its seat should be examined for corrosion or wear as leakage of air at this point will cause the mixture given by the carburetter to be weak.

[*Claudel-Hobson.*

Provided the jets are not damaged or tampered with, they should have a life equal to that of the carburetter.

Removal of Plugs

The foregoing remarks apply to these parts, and only spanners which are a good fit on the heads should be used. Use box spanners whenever possible.

Materials

Wherever possible various aluminium alloys are used for the sake of lightness. In view of the relatively soft nature of these, the utmost care must be taken of screw threads and machined faces to avoid bruising or burring.

Removal of Carburetter from Engine

Before the carburetter can be unbolted at the flange, a number of control rods may have to be removed. This should be done by removing the pins from the fork ends. On no account slacken any adjusting or locking nuts, or alter the angular position or length of any part.

Remove also oil and fuel pipe connections, and handle the carburetter carefully.

Stripping the Carburetter

Where possible, it will be helpful if a sectional drawing of the carburetter be first studied.

On no account remove the throttle plates from the spindle. When all the necessary fixing screws, nuts and connections are removed, the top and bottom halves of the carburetter can be separated. This requires great care, or damage may be done to diffusers, floats, pump mechanism and chokes. If the two halves have not been separated for some time, a light tap with a rubber or leather mallet on the lower portion may be necessary to " break " the joint, but if the two halves still resist separation, examine carefully for fixing screws or similar locking devices which have been overlooked. Slackening off the choke fixing screw often assists the separation of the two halves. See Fig. 13.

Memorise or make a note of the order in which the parts are removed. Clean all parts in pure petrol. Avoid the use of alcohol or alcohol-petrol-benzole mixtures for cleaning purposes. Examine all internal parts and passages for signs of corrosion due to bad fuel, or long-standing deposits of water.

Any signs of corrosion should be removed at the discretion of the person engaged in cleaning, care being taken not to damage machined or jointing faces, calibrated orifices and the like.

Check all valves below fuel level, spring-loaded or otherwise, for freedom of movement and fuel tightness, and after assembly check operation of accelerating pump by filling float chamber with fuel, and moving pump operating lever two or three times.

When bending copper tab washers, care must be taken not to crack the ears. Tab washers must on no account be used more than once.

Whenever possible fit a new body gasket of approved material and *thickness*, as old or broken gaskets may cause leakage of fuel and air, and upset the functioning of the carburetter. The choice of gasket material is important, and only the type recommended by the makers should be used or corrosion may take place at the joint faces.

On no account alter the size or position of the holes in the diffusers.

Float Mechanism

The float needle and seat should have a minimum life of 600 working hours. Never grind needles in their seatings; it will spoil both the needle and the seating. If there are signs of either being defective, fit a new pair. Never fit a new needle in an old seat, or *vice versâ*.

Handle the floats carefully. Do not drop them or bend the float arm, or the float may become poroüs.

Routine inspection will be dealt with in Volume III.

When Dealing with Makers

When referring to the carburetter in correspondence with the makers, always give full particulars of the make and type of engine, the type, serial number and size of carburetter, and the number of the part, which in most cases is marked on it.

Major repairs, such as the fitting of new throttle spindles, etc., should not be attempted. The carburetter should either be returned to the makers, or replaced by a new one.

PRINCIPLES OF FLIGHT

By Sqn. Ldr. Franz Workman, M.C., Ph.D., B.Sc.(Lond.), (Retd.)

All the photographs in this article are reproduced by the courtesy of the Air Ministry ; the air flow pictures were produced by the National Physical Laboratory for the Air Ministry film on " Principles of Flight."

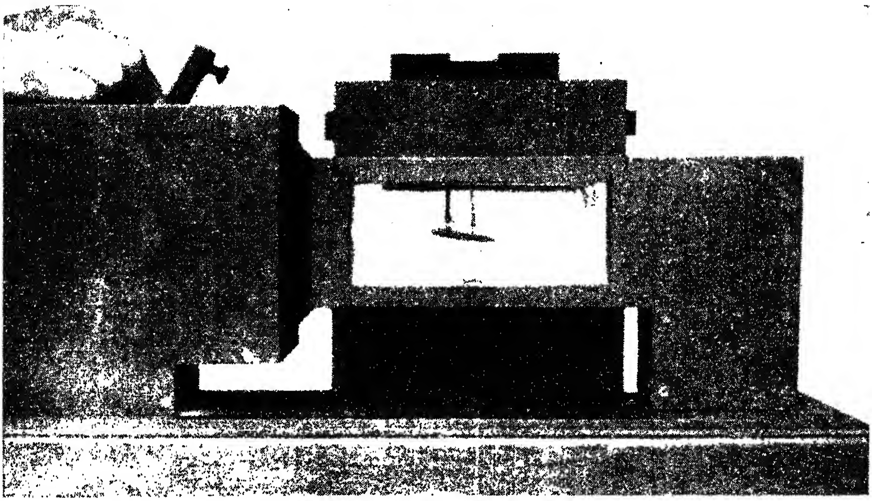


Fig. 1.—An early method of showing air flow.
Using a smoke tunnel with model suspended in stream.

Air Flow

MOST of us have hung over the side of a bridge watching the swirl and play of the water in the wake of a buttress, or in the wake of a buoy anchored in the flowing tide. We know how water behaves because we can see it. Various methods have been developed recently to make air visible, and when we do so we find, as the mathematicians predicted, that it behaves like water.

An Ingenious Method of Studying Air Flow

A method of making air flow visible at high speeds has been developed by the National Physical Laboratory. This method is based upon the fact that the density of air is dependent upon its temperature. By a suitable optical device, hot air can be visually distinguished from cold air.

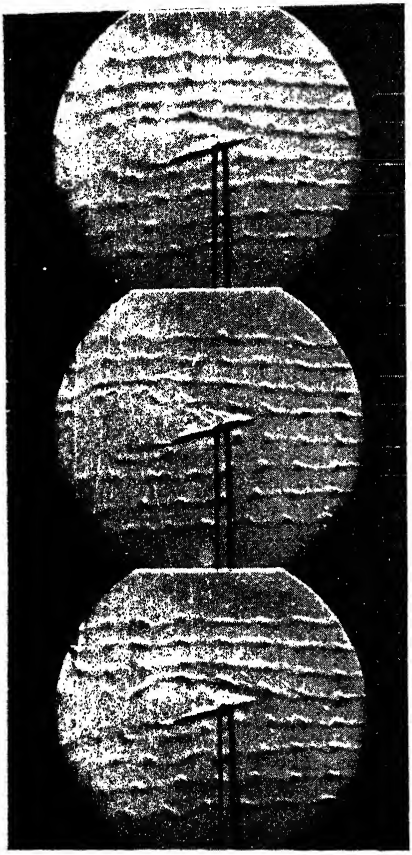


Fig. 2.—AIR FLOW ROUND A FLAT PLATE.

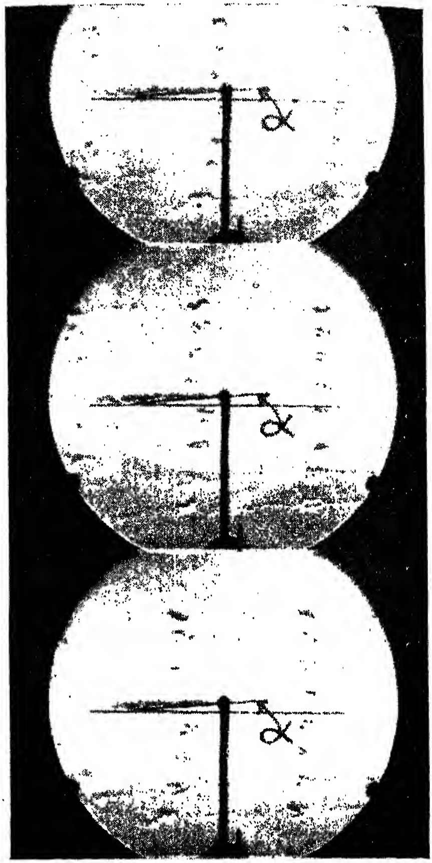


Fig. 3.—ANGLE OF ATTACK.

The horizontal spacing between successive "hot spots" or "spark points" indicates the air speed (see below).

A row of spark gaps is placed in front of the model in the wind tunnel. The sparks heat spots of air and, as the spark terminals remain hot, they heat the air flowing past them. Fine wires heated by electricity are fitted on the back of the model in order to heat the air in its wake (Fig. 2). The whole field of air flow in the vicinity of the model is thus made visible, and its behaviour can be studied at leisure and cine-photographs can be taken showing exactly what happens at normal speed and in slow motion.

Some Examples

Figs. 2 and 3 show the air flow round a flat plate. The small blobs are the spots of hot air heated by the sparks. "α," Fig. 3, is the angle of attack of the plate to the impinging air stream.

The plate deflects the air downwards and retards its flow slightly.

The plate, in deflecting and retarding the air, gets an equal and opposite reaction from the air, represented by the arrow "R," Fig. 4, acting upwards and backwards.

The resultant force on the plate increases as the angle of attack is increased, and reaches a maximum when the plate is flat on to the air flow (Fig. 5, *a* and *b*).

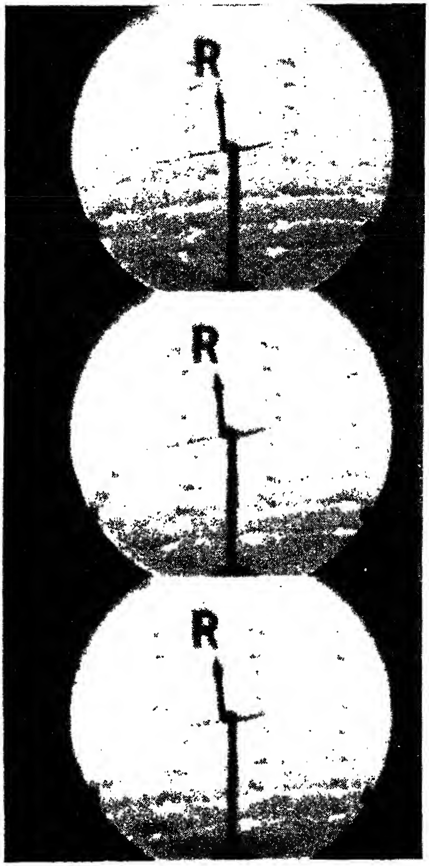


Fig. 4.—RESULTANT AIR FORCE ON A FLAT PLATE.

Stalling

When the angle of attack is increased, the air flow pattern alters suddenly when this angle reaches a certain value. The under surface of the plate continues to deflect the air downwards, but the air flow suddenly comes away from the upper surface right up to the leading edge and leaves a wide turbulent wake behind the plate (Fig. 6).

The angle of attack at which this marked change in the air flow over the plate occurs is called the stalling angle.

The Turbulent Wake shown by the Slow Motion Camera

The movement of the air in the turbulent wake is too rapid to be detected by the eye, but when viewed in slow motion at about one-hundredth of its actual speed, it becomes evident that the turbulent air flows forward up the back of the plate. This feature of the wake is characteristic of the stall.

Fig. 7 shows more of the stalled wake. When viewed in slow motion the blobs of hot air on the edges of the wake can be seen curling back into it from above and below and disappearing in turbulence. It becomes obvious that air is pouring into the wake of the stalled plate from above and below and moving up-stream.

The smooth air flow over the top suddenly comes down again and the wake shrinks when the angle of attack falls just below the stalling angle. There is still a turbulent wake, but the turbulent air flows aft with the rest of the air when the plate is unstalled (Fig. 3).

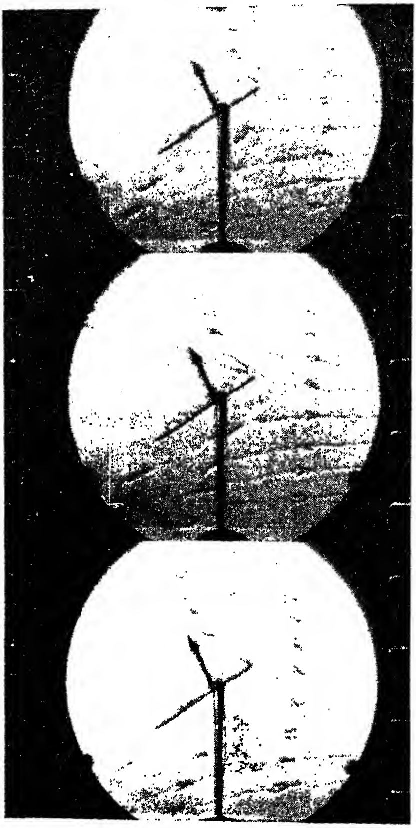


Fig. 5A.

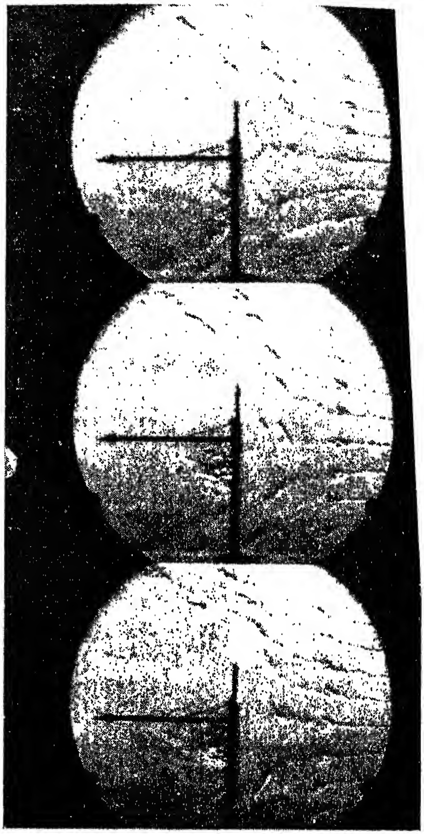


Fig. 5B.

Figs. 5A and 5B.—INCREASE OF RESULTANT AIR FORCE ON A FLAT PLATE WITH ANGLE OF ATTACK.

Motion pictures show that the air flows faster above the plate than beneath it, as well as being deflected downwards. Examination of the spots of hot air on Figs. 2, 3, 4, 5 *a*, 6 and 7 show this.

Skin Friction

Part of the resistance offered by air is due to its viscosity, sometimes spoken of as its "stickiness." The bigger a body, or the greater its velocity, the more important it is that its surface should be as smooth as possible.

Pressure Distribution on a Flat Plate and Resultant Air Force

The flat plate shown in Fig. 8 is supposed to be moving from right

to left. The direction of the relative wind or air flow over the plate is therefore from left to right, as indicated by the arrow.

There are pressures acting all over the surface of the plate. Those on the under surface are greater than atmospheric pressure and are therefore pushing the plate up, while those on the upper surface are less than atmospheric pressure and may therefore be looked upon as pulling the plate up. The sum of all these pressures gives the resultant force on the plate (Fig. 9). The point "O," through which the resultant force acts, is called the centre of pressure (Fig. 10). In the case of a smooth flat plate, the resultant force acts very nearly at right angles to the surface of the plate, except of course when the angle of attack is very small and the plate is moving nearly edge on, when the resistance is mainly due to skin friction.

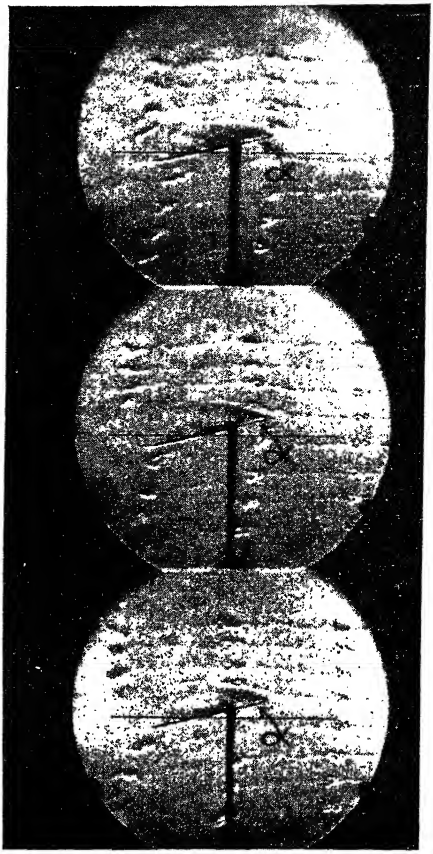


Fig. 6.—THE STALLING ANGLE OF A FLAT PLATE.

Lift and Drag

Purely as a matter of convenience, the resultant force is looked upon as being made up of two forces (Fig. 11). One useful component at right angles to the air flow or relative wind, which is called "Lift," and one undesirable component parallel to the air flow, which is called "Drag."

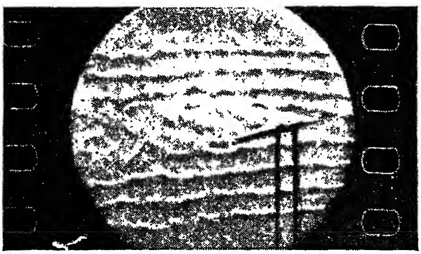


Fig. 7.—THE WAKE OF A STALLED FLAT PLATE.

The direction of motion of the plate in Fig. 11 is shown inclined to the horizontal in order to draw attention to the fact that the lift component of the resultant force is at right angles to the relative wind and therefore only acts vertically when the plate is moving horizontally.

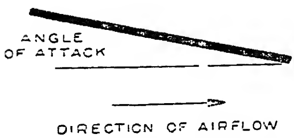


Fig. 8.—DIAGRAM OF FLAT PLATE.

Lift is used to support the weight of an aeroplane to enable it to fly and drag is overcome by the engine and airscrew (Fig. 12).

The resultant force on a moving plate increases as the angle of attack is increased ; and as it continues to act perpendicularly to the surface of the plate it acts further and further backwards (Figs. 13, *a*, *b* and *c*).

The lift increases with the angle of attack at first, but the drag soon increases more rapidly until, when the plate is at right angles to the wind, that is to say when the angle of attack is 90 degrees, there is no lift and the whole resultant force is drag.

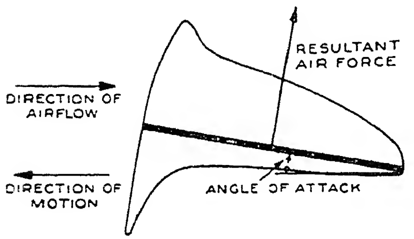


Fig. 9.—PRESSURE DISTRIBUTION ON A FLAT PLATE AND RESULTANT AIR FORCE.

Streamlining

The wake of a plate flat on to the wind is shown in Fig. 14, *a*. Energy is being wasted in maintaining turbulence in the wake and this reacts in exerting drag.

The effect on the air flow pattern of putting a nose on the plate is shown at Fig 14, *b*. There is a slight improvement ; the wake is smaller and the drag is correspondingly reduced.

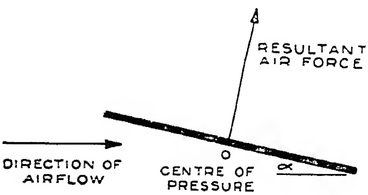


Fig. 10.—CENTRE OF PRESSURE OF A FLAT PLATE.

A short tail is added in Fig. 14, *c*, and has little or no effect on the air flow pattern or the drag.

A longer tail is added in Fig. 14, *d*. The wake has shrunk to very small dimensions and the drag is very much reduced. The plate has been streamlined ; the drag now is mainly due to skin friction.

The main difference between the shapes of the bodies shown in Fig. 14, *c* and *d* (see page 113), is the ratio of their length to their greatest depth. This is called their fineness ratio. The one with the short tail and small fineness ratio fails to streamline the plate at this wind speed, while the one with the long tail and big fineness ratio succeeds in doing so.

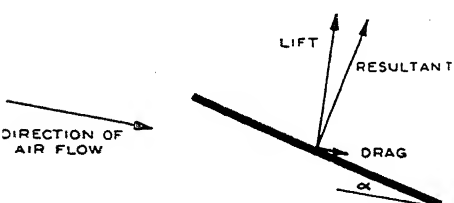


Fig. 11.—RESOLUTION OF RESULTANT FORCE INTO LIFT AND DRAG.

Fig. 15, *a* and *b* (see page 114), shows the wake of a circular wire

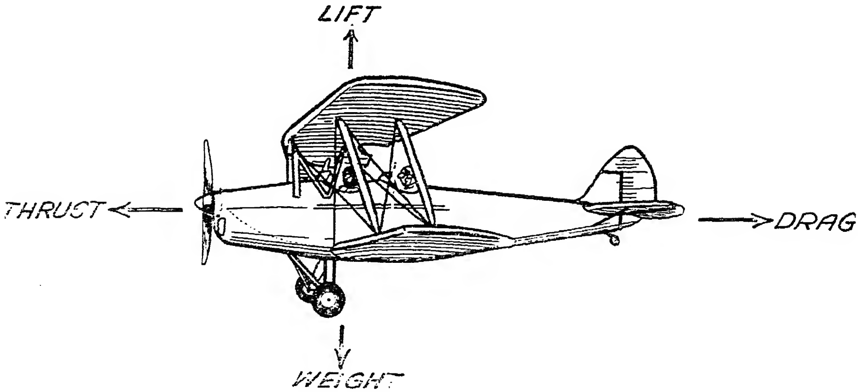


Fig. 12.—THE FORCES ACTING ON AN AEROPLANE.

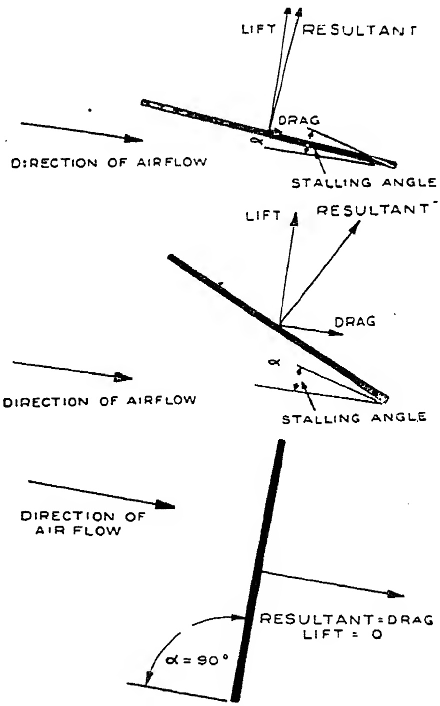
in comparison with the smooth flow round a streamline wire of the same cross sectional area. The streamline wire has a large fineness ratio and its drag is much less than that of the circular wire.

It is thus apparent that everything on an aeroplane which is exposed to the air stream should be streamlined and as smooth as possible in order that the drag may be kept down to a minimum and the top speed increased—or that the horse power required to maintain flight may be reduced.

Cambered Wings

The air can be persuaded to flow smoothly over the stalled flat plate (Fig. 16, *a*), by putting on a curved leading edge (Fig. 16, *b*). The curved leading edge helps the air round the corner, and the stalling angle of the resulting cambered plate (Fig. 17), is considerably greater than that of the original flat plate.

The wings of aeroplanes require to be built-up structures capable of supporting the weight of the aeroplane and its contents. Their structure must be streamlined, and so we get the thick wing section or aerofoil (Fig. 18) which will be found on p. 116.



Figs. 13A, 13B, 13C.—EFFECT OF ANGLE OF ATTACK ON THE RELATIVE MAGNITUDES OF THE LIFT AND DRAG OF A FLAT PLATE.

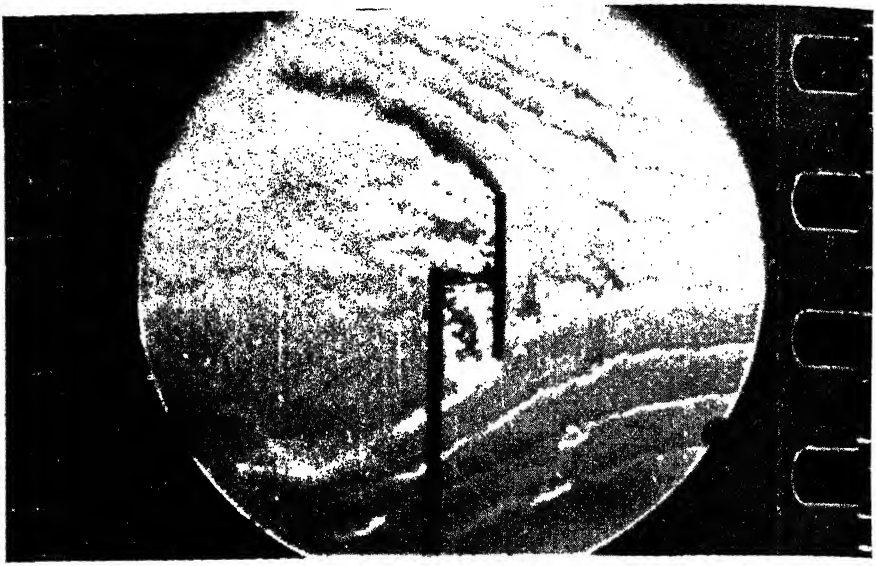


Fig. 14A.—STREAMLINING A FLAT PLATE.

Energy is being wasted in maintaining turbulence in the wake and this reacts in exerting drag.

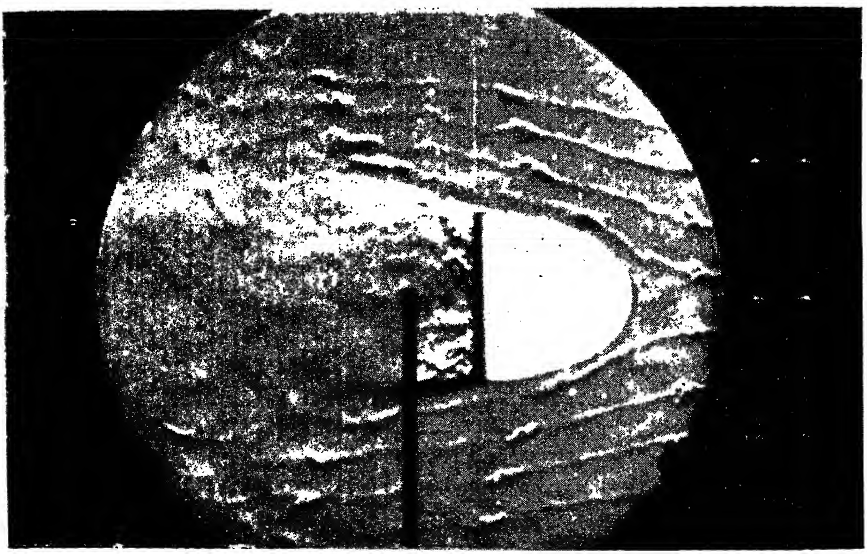


Fig. 14B.—STREAMLINING A FLAT PLATE.

Showing effect of putting a nose on the plate.

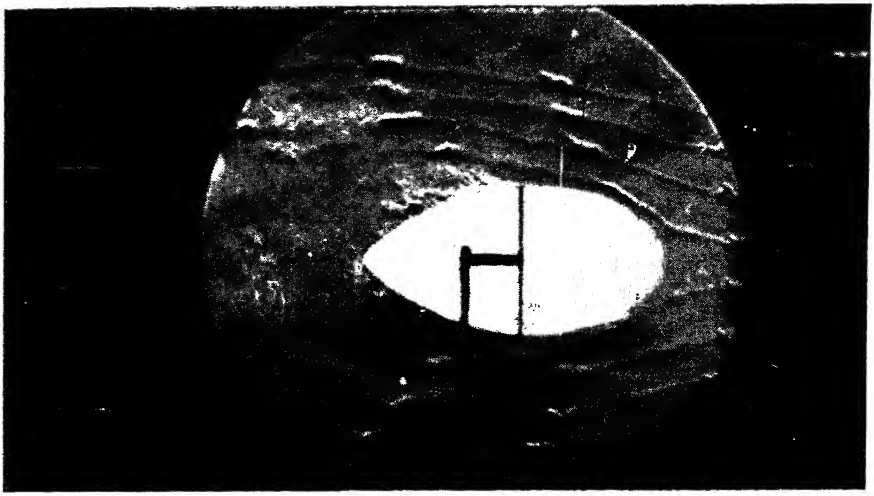


Fig. 14C.—Streamlining a flat plate.

Showing addition of short tail. In order to show the effect more clearly, the plate is arranged at right-angles to the air flow. The effects shown in this and the following picture would be just the same if the plate were arranged edgewise in the air stream, but owing to the thinness of the plate the air flow could not be so easily followed.

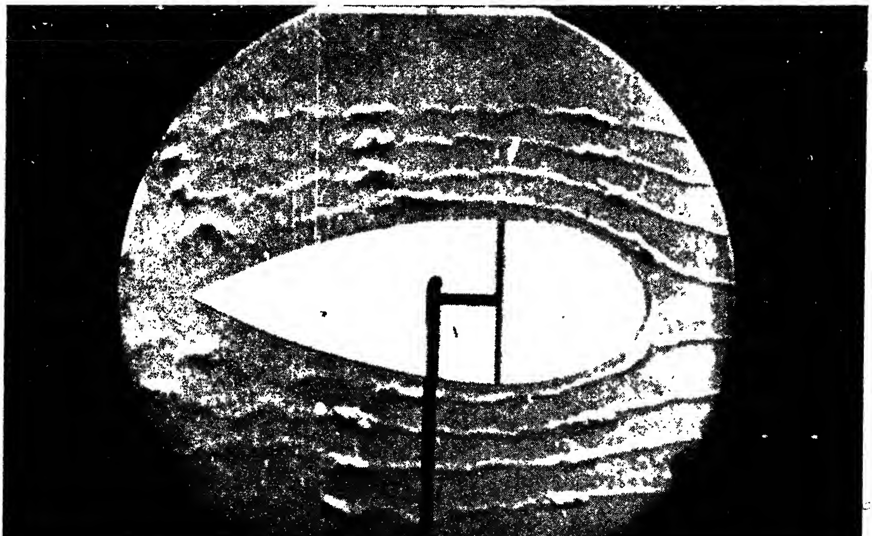


Fig. 14D.—Streamlining a flat plate.

Showing addition of longer tail. Comparing this with the previous figure, it will be seen that the wake at the tail has now almost entirely disappeared.

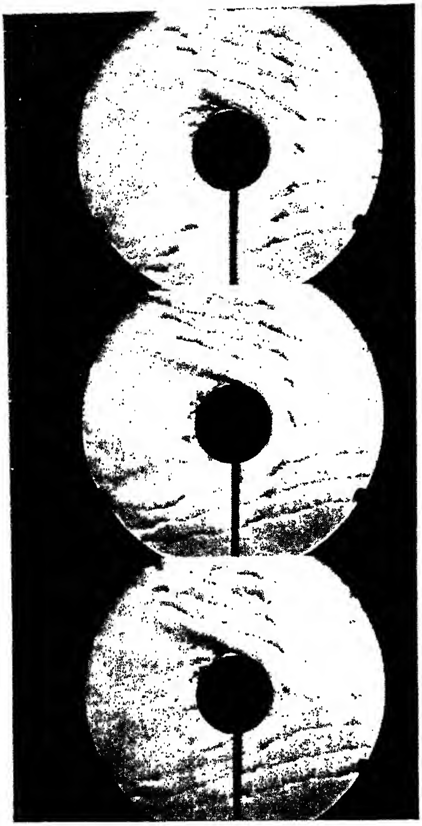


Fig. 15A.

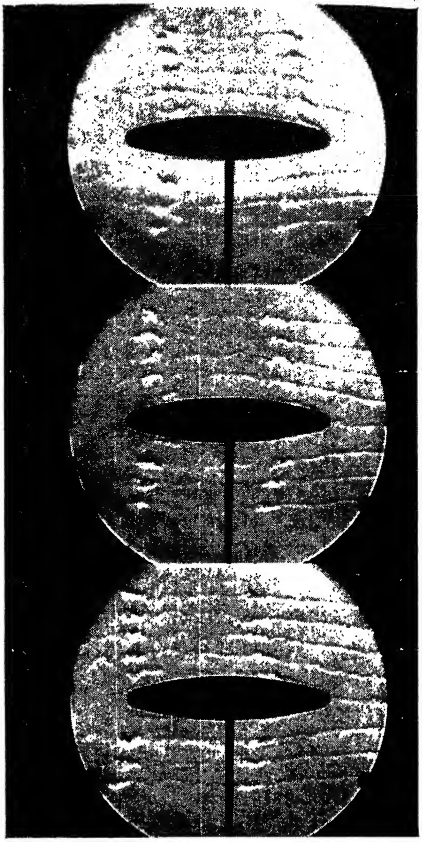


Fig. 15B.

Figs. 15A and 15B.—AIR FLOW ROUND A CIRCULAR WIRE COMPARED WITH THAT ROUND A STREAMLINE WIRE OF THE SAME CROSS-SECTIONAL AREA.

The air flows smoothly under and over good cambered wing sections with very little turbulence, until a large angle of attack is reached and the aerofoil stalls (Fig. 19, *a* and *b*).

The change in the character of the flow pattern at the stalling angle is similar to the change which takes place in the case of the flat plate. When the aerofoil stalls the turbulent air commences to flow forward up the back of the aerofoil and the smooth air flow leaves the top surface. Air flows into the wake from above and below.

The stalling angle and the suddenness with which the stall occurs depend largely upon the shape of the top surface in the vicinity of the leading edge. Generally speaking, other things being similar, a thin aerofoil section should have a larger stalling angle and stall less suddenly than a flat plate and a thick aerofoil section should have a larger stalling angle

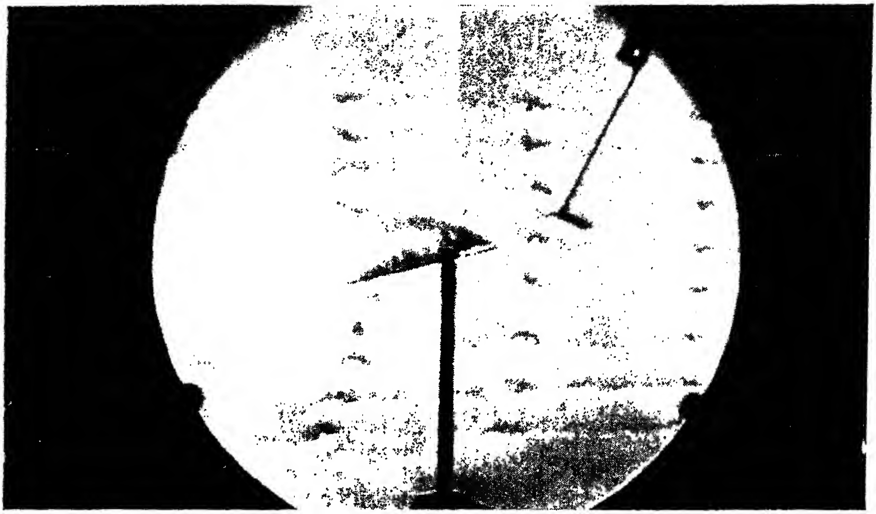


Fig. 16A.—A FLAT PLATE ARRANGED AT THE STALLING ANGLE IN AIR STREAM.

Note the turbulent wake behind the upper edge of the plate, due to the air stream having broken away from the upper surface of the plate.

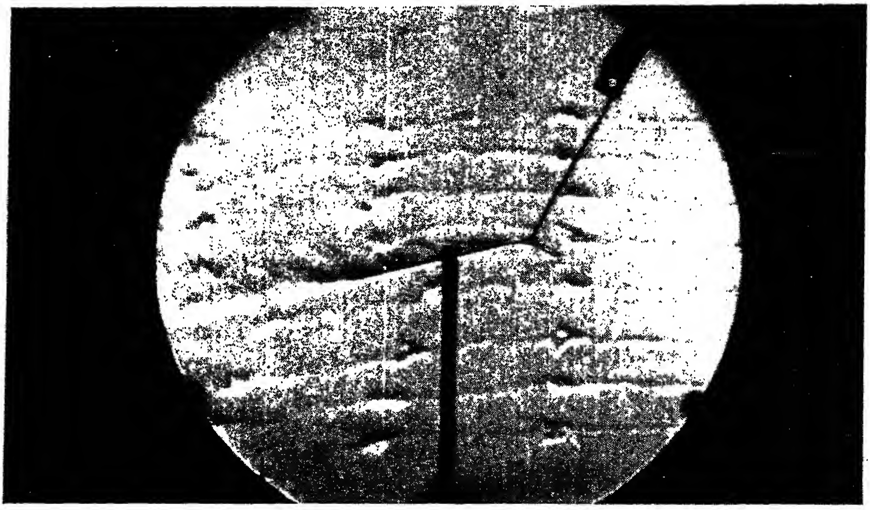


Fig. 16B.—EFFECT OF PUTTING A CURVED LEADING EDGE ON A STALLED FLAT PLATE.

The plate is at the same angle as in the previous picture, but the stalling effect has disappeared.

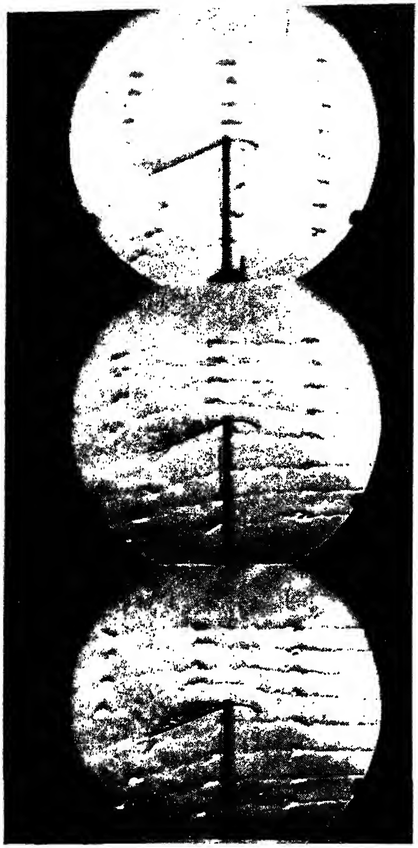


Fig. 17.—STALLING ANGLE OF A CAMBERED PLATE.

This is considerably steeper than for a flat plate.

and stall less suddenly than a thin one. The rate of change of curvature of the path which the air must follow in order to continue to flow smoothly over the top surface appears to be a controlling factor. When the curvature over the leading edge changes too rapidly, the air does not appear to be able to "get round" in time and therefore tends to leave the top surface.

As the pressure on the upper surface is below atmospheric pressure, the surrounding air tends to flow into this region of lower pressure. The slightest departure of the air flow over the top results in a wider "opening" for the surrounding air to flow in from the trailing edge. When, on stalling, the surrounding air commences to flow in from the rear it relieves the reduction of pressure on the upper surface which was helping the smooth air flow to "get round" and the smooth air flow breaks away from the top surface altogether.

Ice Formation

Fig. 20 shows what happens when ice forms on the leading edge of an aeroplane wing. The ice spoils the shape by introducing too sudden a change of curvature on top; the air flow therefore breaks away from the top surface and the wing stalls at a comparatively small angle of attack. The lift is reduced and the drag is increased accordingly, with the result that the aeroplane may be unable to maintain height and be forced to land.

The Handley Page Slat

The Handley Page slat consists of a small auxiliary aerofoil which, when placed in front of the leading edge of a wing, helps the air round the corner and prevents the disastrous formation of a wide turbulent wake (Fig. 21, *a* and *b*).

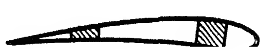


Fig. 18.—THICK WING SECTION OR AEROFOIL.

The Handley Page slat is spring-loaded to

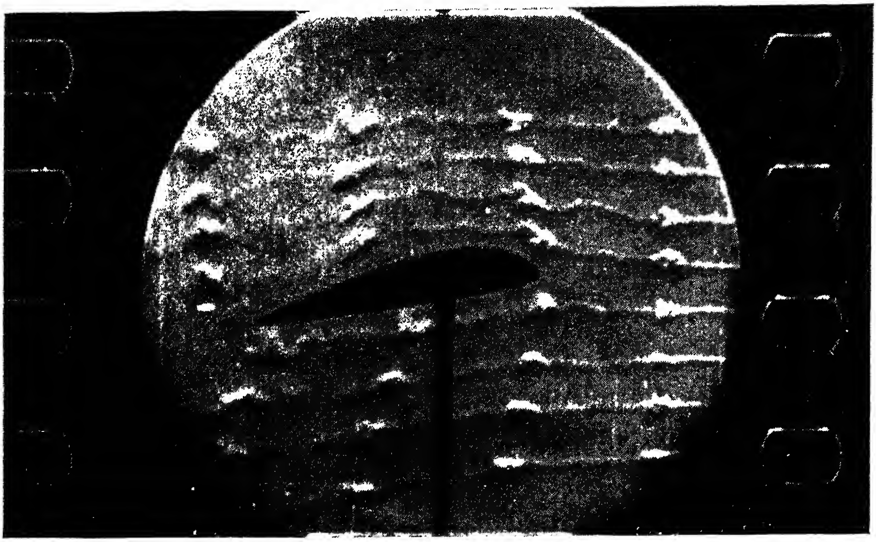


Fig. 19A.—SMOOTH FLOW ROUND A GOOD CAMBERED WING SECTION.

The regular spacing of the hot spots produced by the spark gaps and also the absence of a turbulent wake, demonstrate the smoothness of the air flow. Note that a flat plate arranged at the same angle as the above would be in the stalling position.

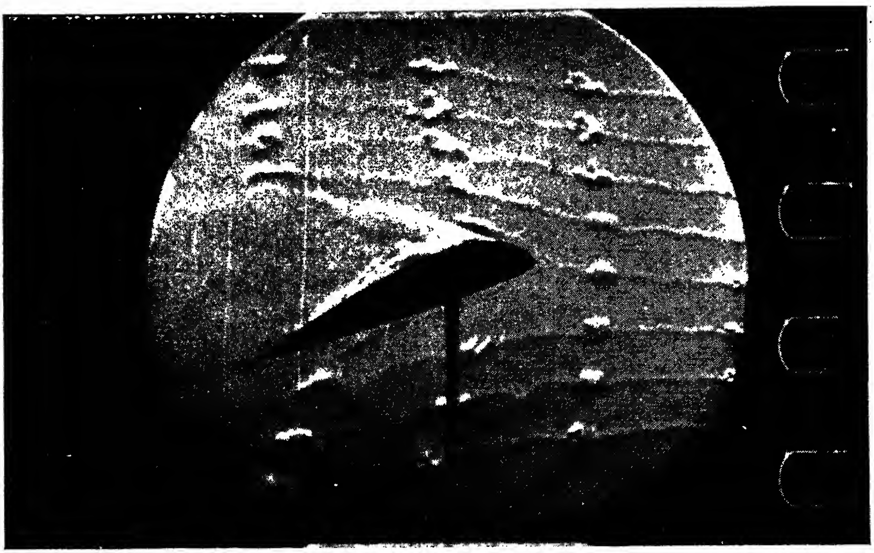


Fig. 19B.—LARGE STALLING ANGLE OF A GOOD CAMBERED WING SECTION.

This illustrates the very large angle of attack which can be utilised with a properly cambered wing section before stalling occurs.

Fig. 20.—EFFECT OF ICE FORMATION ON THE LEADING EDGE OF AN AEROPLANE WING.

keep it closed in normal flight (Fig. 22). When the angle of attack is increased to what would normally be its stalling angle, the depression or suction on the upper surface of the leading edge increases considerably and pulls the slat forward and upwards, thus opening a slot between the slat and the leading edge (Fig. 23).

The Townend Ring

Figure 24 shows how the cylinders of a radial engine divert the air away from its streamline engine nacelle and result in a wide turbulent wake with consequent heavy drag.

The Townend ring is a ring of aerofoil cross section, which is mounted as shown in Fig. 25. The angle of attack of the ring to the local air flow is such that it leads the air round and down over the body, reducing the turbulent wake behind the cylinders and reducing their drag and interference with the air flow over the nacelle.

The air pressure inside these aerofoil section rings is greater than that on their outer surface. Their setting is such that the resultant force on them acts slightly forward. Such rings must, therefore, be fitted securely, as, if they come adrift, they would move forward and foul the airscrew (Fig. 26).

Pressure Distribution on an Aerofoil

The pressure per square inch over the surface of various aerofoil sections has been measured. Fig. 27 shows them plotted diagrammatically. As in the case of a flat plate, the pressures on the under surface act generally upwards, while those on the upper surface are mostly less than atmospheric pressure and therefore also act upwards. The enclosed areas approximately represent the forces on the under and

Fig. 21A.—Showing a cambered wing in stalling position.

The small aerofoil on the right represents the Handley Page Slat which has not yet been brought into effective operation.

Fig. 21B.—Effect of the Handley Page slat on a stalled wing.

The slat has now been brought into position. Note how the turbulent wake has disappeared. The wing is no longer stalled.

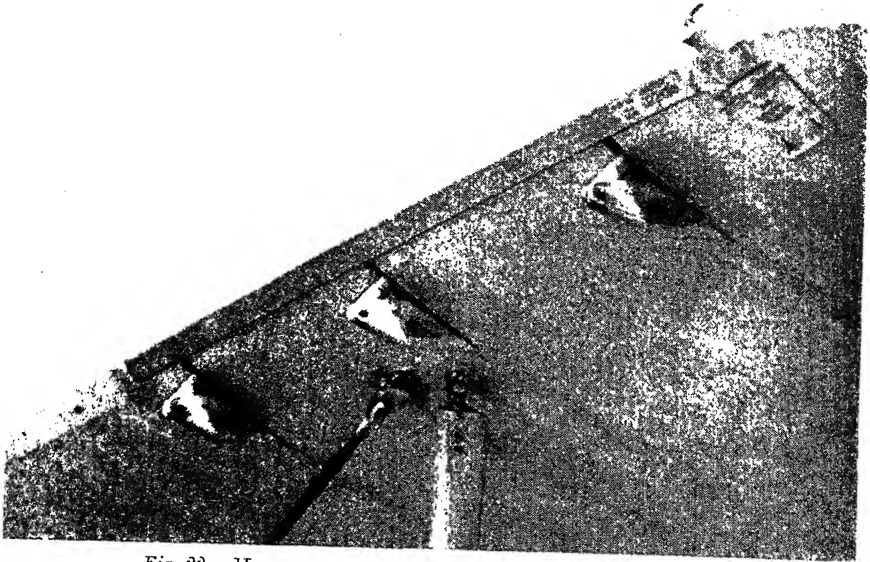


Fig. 22.—HANDLEY PAGE SLOT CLOSED IN NORMAL FLIGHT.

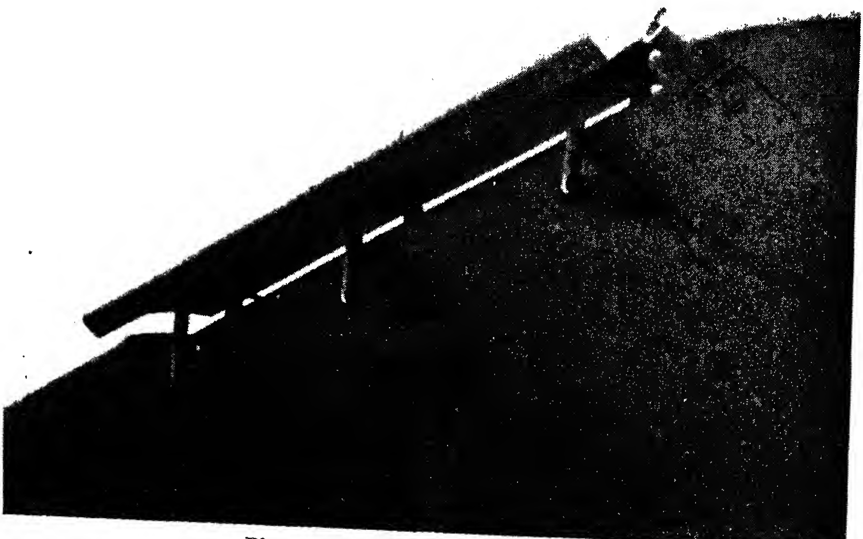


Fig. 23.—HANDLEY PAGE SLOT OPEN

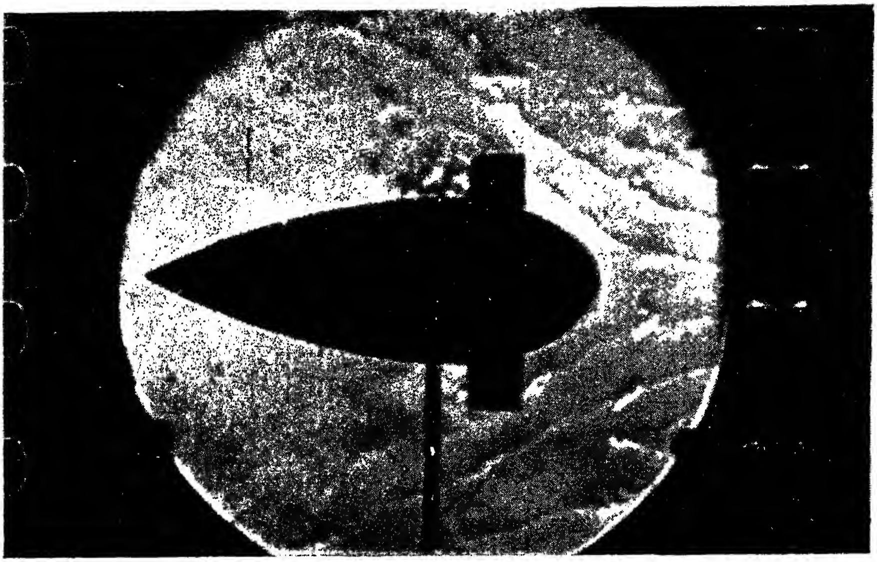


Fig. 24.—AIR FLOW OVER A RADIAL ENGINE.

Note the air pockets behind the engine cylinders. These produce turbulence and undesirable drag. The next illustration shows how this can be avoided.

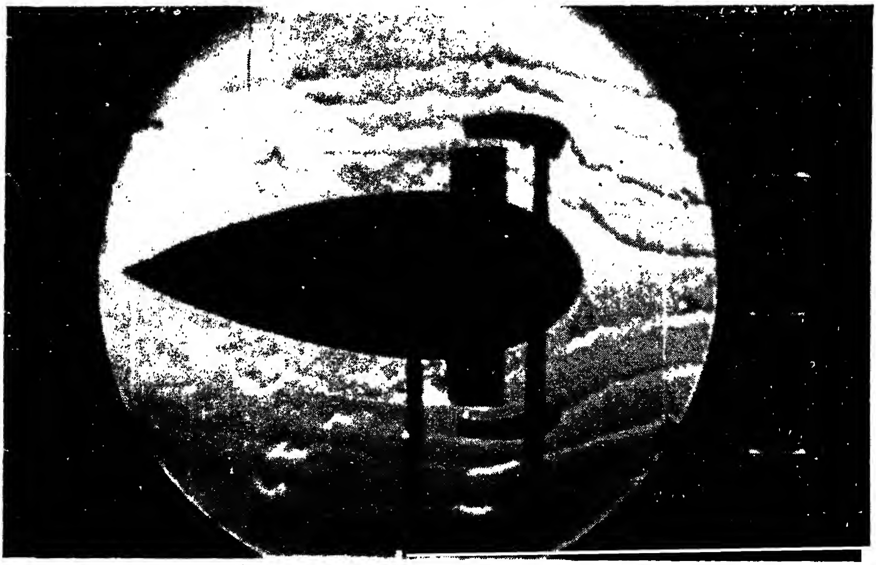


Fig. 25.—EFFECT OF THE TOWNEND RING ON THE AIR FLOW OVER A RADIAL ENGINE.

The ring directs the air flow into the air pockets shown in the previous picture, and so eliminates the turbulent wake.

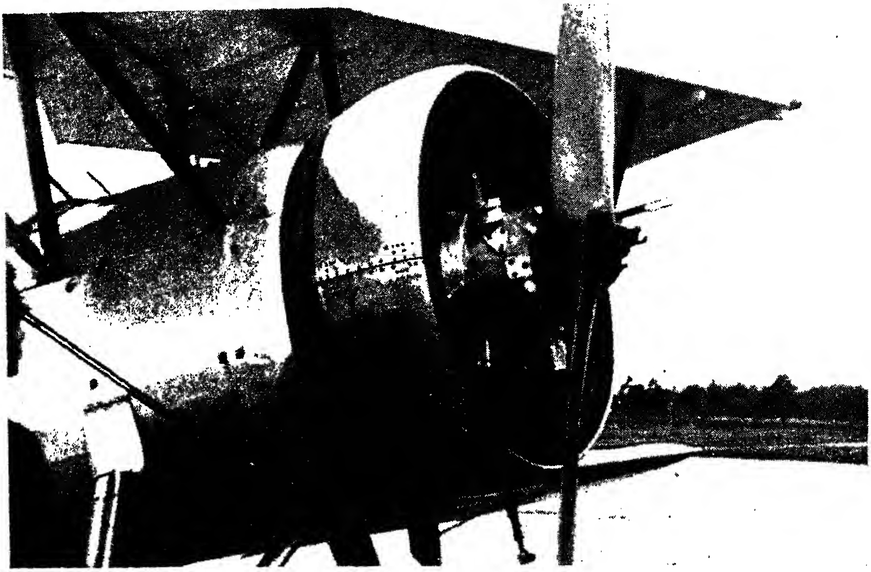


Fig. 26.—THE TOWNEND RING.

upper surfaces. About three-quarters of the total force is exerted on the upper, and only about one quarter on the under surface at the angles of attack used in normal flight.

The resultant force acts well forward of the middle of the aerofoil section. On a good aerofoil section the resultant force acts more nearly perpendicularly to the air flow than is the case with a flat plate.

The lift of an aerofoil is therefore larger in comparison to its drag than that of a flat plate (Fig. 28).

Lift and Drag Coefficients

All the air flow pictures shown above were taken in the same wind tunnel; the models were all about the same size and the wind speed was more or less the same in each case. It is obvious that the marked differences in the behaviour of the air flow round the various bodies were due to differences in their shape and their attitude to the wind.

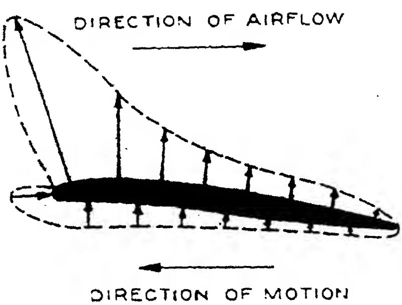
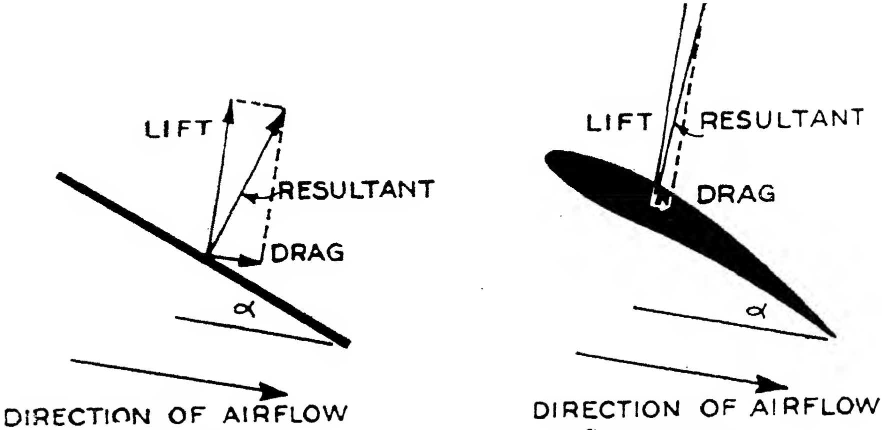


Fig. 27.—PRESSURE DISTRIBUTION ON AN AEROFOIL.

It should therefore be clear that the lift of an aerofoil must be proportional to some quantity which is dependent upon its shape and upon its angle of attack. This quantity is called the lift coefficient of the aerofoil section.



FLAT PLATE. CAMBERED WING.

Fig. 28.—COMPARISON OF THE LIFT AND DRAG FORCES ON A FLAT PLATE AND ON AN AEROFOIL.

Similarly, the drag is proportional to a quantity called the drag coefficient of the aerofoil section.

The bigger the surface area of an aeroplane wing, the more air it affects in flight.

The denser the air, the greater the force required to displace it.

The greater the velocity of the wing, the more rapidly it displaces the air, and in flight the force on a wing is found to be proportional to the square of its velocity.

The lift component of the resultant force on an aeroplane wing must therefore be proportional to :—

The lift coefficient of the aerofoil section,
The density of the air,
The area of the wing and
The square of the velocity.

The drag coefficient of the resultant force must similarly be proportional to :—

The drag coefficient of the aerofoil section,
The density of the air,
The area of the wing and
The square of the velocity.

The lift coefficient of an aerofoil section is shown plotted against the angle of attack in Fig. 29. The lift coefficient increases rapidly to a maximum at the stalling angle and falls suddenly as the stalling angle is passed and turbulence starts on the upper surface.

The drag coefficient curve is shown at Fig. 30. The drag coefficient increases slowly from a small value at small angles of attack and more rapidly as the angle of attack is increased, until, at the stalling angle, it

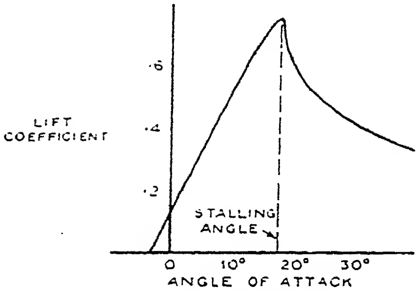


Fig. 29.—THE LIFT COEFFICIENT OF AN AEROFOIL PLOTTED AGAINST ANGLE OF ATTACK.

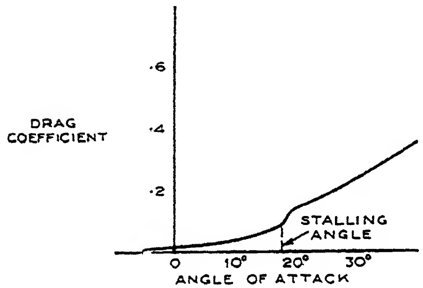


Fig. 30.—THE DRAG COEFFICIENT OF AN AEROFOIL PLOTTED AGAINST ANGLE OF ATTACK.

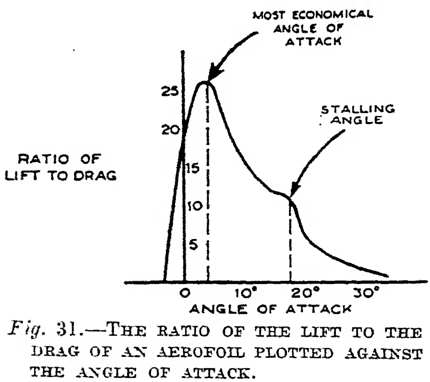


Fig. 31.—THE RATIO OF THE LIFT TO THE DRAG OF AN AEROFOIL PLOTTED AGAINST THE ANGLE OF ATTACK.

increases suddenly and continues to increase rapidly as the angle of attack is increased beyond the stall.

A measure of the efficiency of an aerofoil section is the ratio of its lift to its drag coefficient.

The ratio of the lift to the drag of an aerofoil section is shown plotted against the angle of attack in Fig. 31. It rises rapidly as the angle of attack increases, reaches a maximum well before the stalling angle, then falls rapidly.

The most economical angle of attack at which to fly is that at which the ratio of the lift to the drag is a maximum. In the case of wings of this particular aerofoil section, the most economical angle of attack is about $4\frac{1}{2}$ degrees, and less horse power is required per pound of lift obtained at this angle of attack than at any other angle.

Stalling Speed

It has been shown that the lift of an aeroplane wing is proportional to the lift coefficient of its aerofoil section, the density of the air, the area of the wing and the square of its velocity.

If we reduce the velocity we must therefore increase the lift coefficient in order to maintain flight.

When the lift coefficient reaches its maximum value at the stalling angle (Fig. 32), the velocity then required to maintain flight is called its stalling speed.

In level flight, for example, an aeroplane is said to be flying at its stalling speed when it is just maintaining level flight, with its wings at their stalling angle—and therefore maximum lift coefficient.

Effect of the Handley Page Slat on the Lift Coefficient and Stalling Speed

The lift coefficient of a wing section with and without a Handley Page

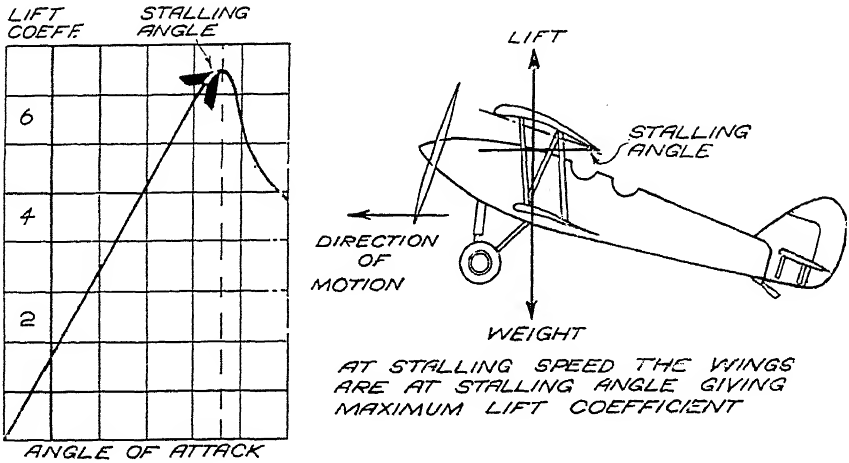


Fig. 32.—DIAGRAM ILLUSTRATING THE DEFINITION OF STALLING SPEED.

slat is shown plotted against the angle of attack in Fig. 33. The lift coefficient goes on increasing to a much larger angle of attack when the slot is open before the wing stalls. The stalling speed of an aeroplane fitted with Handley Page slats is reduced accordingly.

Landing Speed

The landing speed of an aeroplane is the lowest speed at which it can safely alight.

When an aeroplane is flying close to the ground, the ground interferes slightly with the air flow beneath the lower planes. This results in a slight increase of lift at the same angle of attack and speed. Level flight can therefore be maintained at a slightly lower speed when very close to the ground if the wings can be put at their stalling angle. It may, however, be impossible to put the wings at their stalling angle when very close to the ground without putting the tail skid on the ground first, in which case the landing speed will normally be higher than the stalling speed, unless wing flaps are used. These, when dropped, increase the effective angle of attack, the lift and the drag of the wings, without altering the attitude of the aeroplane.

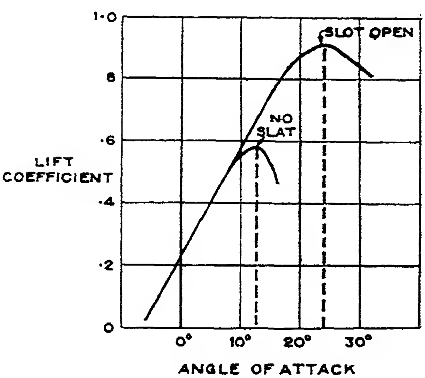


Fig. 33.—EFFECT OF THE HANDLEY PAGE SLOT ON THE LIFT COEFFICIENT AND STALLING ANGLE OF AN AEROPLANE WING.

QUESTIONS AND ANSWERS

Mention one of the Earliest Methods of Studying the Aerodynamics of Flight.

A scale model of the aeroplane or aerofoil was arranged in a smoke tunnel with glass observation windows. The smoke or fumes of stannic chloride were fed into the air stream so that the air flow could then be observed under various conditions, corresponding to those obtaining on a full-size aeroplane under actual flight. See Fig. 1, p. 105.

What was the Disadvantage of this Method ?

At high air speeds the swirling of the smoke rendered accurate observation impossible. It was also very difficult to obtain photographic or other permanent records.

What is the Latest Method which has been Developed by the National Physical Laboratory ?

A row of spark gaps is arranged in the air stream. Sparks pass between the terminals at stated intervals, and thus produce heated streams of air. (See Fig. 2.)

If the air flow is steady, light transmitted through the air stream would produce a series of straight parallel lines on a photographic plate. At equal intervals along these lines would appear bulges, which represent the sparking periods. By measuring the space between these bulges, the velocity of the air stream at any point can be calculated. The paths of the various portions of the air stream can also be accurately observed.

Do the Spark Gaps Render the Air Flow Visible ?

Not to the eye, but to the camera or cine-camera. The heated streams of air alternate with cooler streams. When the air stream is photographed by transmitted light, the hot and cold strata show up clearly.

What Additional Provision is made to Render all Portions of the Air Stream Visible on the Photographic Plate ?

Fine wires, heated by electricity, are sometimes fitted on the back of the model, in order to heat the air in its wake.

What Happens when a Flat Plate is at a Slight Angle to an Approaching Air Stream ?

(1) The plate deflects part of the air stream downwards and retards its flow slightly.

(2) An upward thrust is exerted by the air on the plate.

(3) The upper portion of the air stream passes closely along the upper surface of the plate.

(4) A rearward force or " drag " is exerted on the plate by the moving air stream.

What is Meant by " Angle of Attack " ?

If a plate is arranged in an air stream, edge-on to the direction of the flow, so that the surface of the plate is parallel to the direction of flow, the plate has no angle of attack. If the leading edge of the plate, *i.e.*, the edge which meets the oncoming air, is raised whilst the trailing edge is kept in its original position, the plate is now at an angle to the direction of the air flow. This is called the angle of attack. Briefly, it is the angle between the plate surface and the approaching air stream.

What is Meant by " the Stalling Angle " ?

When the angle of attack is small, the leading edge of the plate splits the air stream into two portions. The lower portion is deflected downwards by the under side of the plate, and the upper portion passes closely over the top surface of the plate. When the angle of attack is increased beyond a certain value, the top portion of the air stream suddenly comes away from the upper surface of the plate, producing a wide turbulent wake behind the plate.

The angle at which this occurs is called the stalling angle.

What is Meant by " Lift " ?

A plate which presents an angle of attack to an approaching air stream experiences a resultant force at right-angles to the surface. This resultant force can be split up into two parts, one parallel to the air flow, and one at right-angles to the air flow.

The force acting on the plate at right-angles to the air flow is called the lift.

What is Meant by " Drag " ?

In the conditions referred to above, the force acting upon the plate in the direction of the air flow is known as the drag.

What Angle of Attack would give the Greatest Resultant Force on a Flat Plate, Acted upon by an Air Stream ?

Ninety degrees. In this case the whole of the resultant force would be in the direction of the air flow, *i.e.*, it would be a drag force, with no lift.

What Angle of Attack would give the Maximum Lift on a Flat Plate ?

An angle slightly less than the stalling angle. This would vary according to the dimensions and shape of the plate or aerofoil.

If a Flat Plate is Arranged Edge-on to the Air Flow, what Force is Exerted on it by the Air ?

As a turbulent wake is formed behind the rear edge of the plate, a drag is exerted.

How can this Drag Effect be Minimised?

By putting a rounded nose on the front or leading edge of the plate, and a tapered tail on the rear or trailing edge of the plate. This is known as streamlining.

Why does Streamlining Reduce the Drag?

Because it enables the air to flow smoothly from the leading edge of the plate to the tip of the trailing edge without forming a turbulent wake.

In Addition to Streamlining, what other Improvement can be made to a Flat Plate to Improve the Available Lift?

The leading edge may be curved (compare Figs. 16a and 16b). This has been found to retard stalling, so that the stalling angle can be appreciably larger.

In what way is Ice Formation on the Leading Edge of the Aeroplane Wing Detrimental?

The ice introduces too sudden a change of curvature on the top of the leading edge. The air is deflected away from the upper surface of the plane instead of being able to follow closely the wing contour. The air flow breaks away from the top surface of the wing, which will then stall at much below the natural stalling angle.

In what way is the Handley-Page Slat Advantageous?

When the slat is opened it helps the air to flow along the upper surface of the wing, thus preventing stalling under conditions where it would otherwise occur.

What is the Townend Ring?

A ring of aerofoil cross section which is arranged concentrically outside the cylinders of a radial engine.

What is its Object?

To direct the air flow round and down behind the engine cylinders, which otherwise form a turbulent wake. By preventing the formation of this wake, the Townend ring reduces the drag appreciably.

Why is it of Vital Importance to Fix Townend Rings Securely?

Because they are arranged in such a manner that the resultant force acts on the rings in a slightly forward direction. If a ring became loose it would move forward and foul the airscrew.

ROUTINE CARBURETTER TUNING

By E. W. Knott, M.I.A.E., M.S.A.E.

LET it be assumed that an engine is fitted on the test bench complete with all necessary controls, instruments, etc., and that the proper size and type of carburetter as jointly arranged between the engine manufacturer and the carburetter manufacturer is fitted. The carburetter manufacturer—from long experience—will know from the engine capacity and revolutions approximately what size choke tube will be necessary and also what size jets will at least start and run the engine even if not quite satisfactorily. Usually they deliberately err on the rich side.

Starting the Engine

The throttle stop screw should be slacked back until clear of the throttle stop and then screwed in until the throttle has a minimum opening of about 3 or 4 degrees and the screw locked. The mixture control should be checked to see that it is in the normal closed (ground) position, and after making sure that all controls, etc., are correct, the cooling air or water (as well as for the dynamometer) may be set going and the engine started up by means of the electric motor fitted to the dynamometer, from which all load should be removed. It will first be necessary to aid starting by priming some of the cylinders with fuel either by hand through the exhaust valve ports if no exhaust pipe is fitted, or, as is more common, injecting fuel through piping specially fitted for that purpose and fed by a hand pump such as the Kigass. Where the carburetter is fitted with an accelerating pump, and is of the inverted type, starting up is often made easier if the throttle is opened to about half full opening and closed again several times, the extra fuel injected into the air stream giving the required richer mixture. Once the engine has fired a few times it may continue to run, or, on the other hand, may require nursing by slow steady injections from the Kigass priming pump. Rapid turning of the hand starting magneto (booster magneto) may also help to keep it going until warm enough to run, even if unsteadily. Once the engine is started it should be opened up to about 700 or 800 revolutions and allowed to warm up.

Adjustment of Slow Running Mixture

If the engine repeatedly fires a few times and then stops, either the slow running mixture is too weak or the throttle is not opened wide enough, probably the former, and the slow running mixture should be richened up. If the mixture is too rich, black smoke will issue from the

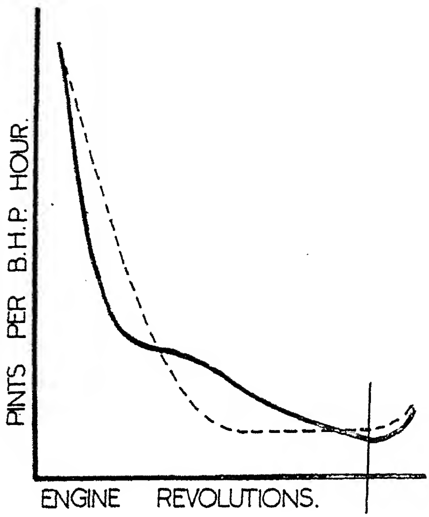


Fig. 1.—First trial throttle curve.

Dotted line shows desired curve and heavy line the probable one.

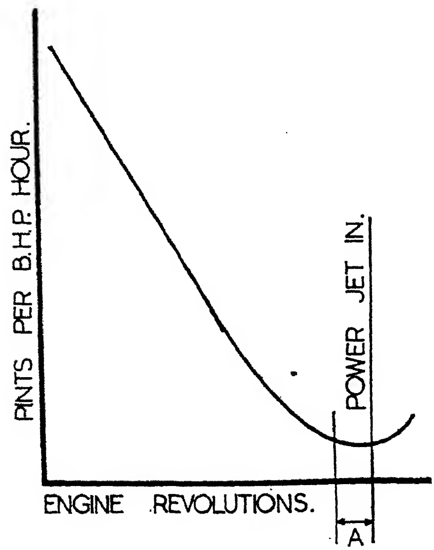


Fig. 2.—Throttle curve for small engines fitted with carburetters having no accelerating pump.

Cruising range A is relatively small.

exhaust outlets and the mixture should be adjusted until—when warmed up—the engine fires evenly. It is better to keep the mixture a little on the rich side than on the weak, as it aids starting and has some influence on acceleration. The throttle stop screw can then be slowly screwed out until the required slow running speed is obtained, and this reduction in speed may require a slight change in mixture strength to keep the engine firing evenly. Too low a slow running speed may cause the engine to stop when landing after a long glide, particularly if the carburetter is a small one without an accelerating pump. On the other hand too high a slow running speed will increase the landing speed of the machine and speeds usually vary between 300 and 500 r.p.m., according to circumstances.

When ready, the throttle can be opened up gradually to cruising speed at intervals of 100 r.p.m. and the main jet altered to give the correct fuel consumption, *i.e.*, the correct pints per horse power hour. At about 9/10 full power, the power jet should be adjusted to come into action, and here again a size of jet is chosen which gives the correct pints per horse power hour with the throttle opening giving normal boost. At this point the brake adjustment should be locked.

The Throttle Curve

Cruising and full power consumptions vary with different makes of engine, and 0·55 pints

per b.h.p. hour is an approximate figure for cruising and 0·6 for full power. Figures below these are often attained, but if taken too low cause high temperatures and much oil burning. Having fixed these two points, a whole throttle curve may be taken, either from full power downwards or from slow running upwards. Irregularity in running and in the sound of the exhaust note may be observed at certain speeds, and the cause of these can be fairly accurately determined by an examination of the throttle curve when drawn.

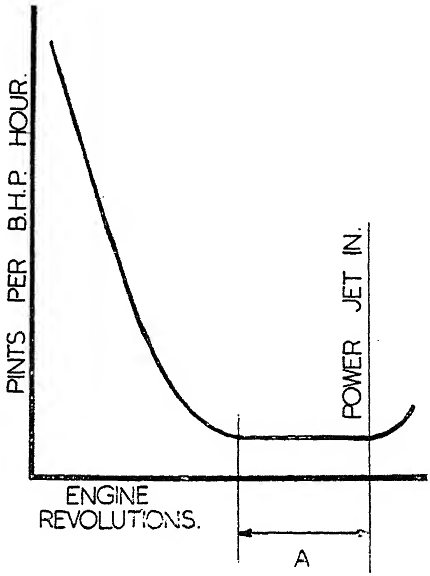


Fig. 3.—THROTTLE CURVE FOR LARGE ENGINES WITH CARBURETTER FITTED WITH ACCELERATING PUMP.

Note the large cruising range A.

Probably the first throttle curve will appear something like Fig. 1, unless a large element of luck accompanies the trial setting. The consumption at tick-over speed is correct, which shows that the quantity of fuel issuing from the hole opposite the throttle is correct. As however the throttle is opened a little, the curve drops away, showing that the mixture is too weak. At this throttle opening the second slow running discharge will be under suction and is obviously not feeding enough fuel. It should therefore be made a little larger. As this will admit more air when the throttle is in the tick-over position, the mixture there will be made weaker and must be brought back to its original strength by means of the mixture adjusting screw. If it is found that the range of adjustment on this screw is insufficient to get the required richness, it is a sign that the slow running jet is too small, and larger jets should be fitted until the mixture screw has a margin of adjustment on either side of the correct setting, *i.e.*, it can be made too weak or too rich.

The early part of the throttle curve should then be run again to see if the bumps are flattened out and the engine then run at steadily increasing speeds of say 200 r.p.m., power and consumption figures being taken at each speed. When approaching the point where the power jet comes in, readings are best taken at 100 r.p.m. intervals. If the diffuser comes into action too late there will again be a drop in the curve, but farther along than that given by the second slow running discharge hole. If it comes in too early or with a rush instead of gradually merging with the feed from the second S.R. hole, the curve will have a " kick-up " at the

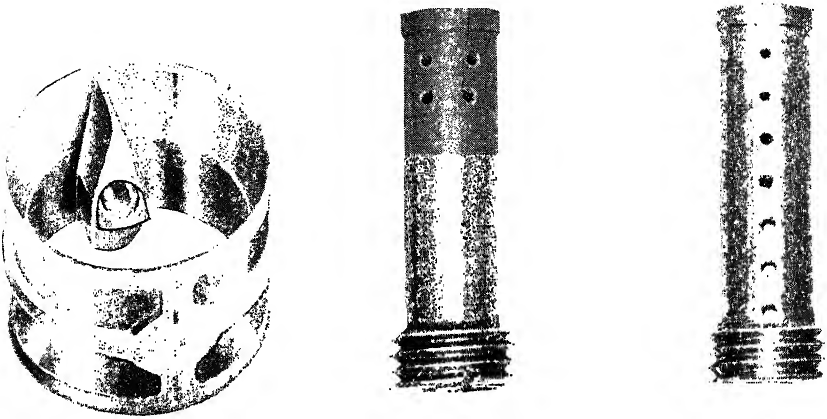


Fig. 4.—Two types of diffuser with choke tube of streamline type.

lower part of the cruising range. Again, the curve through the cruising range may have a tendency to either rise or fall steadily instead of being flat, and the size, position and number of the holes in the diffuser are varied to obtain this result. Reducing the number and/or the size of holes will reduce the amount of air entering the diffuser and will tend to make the curve go gradually richer, *i.e.*, upwards towards full power. Increasing the amount of diffuser air will make the curve drop.

The Diffuser

In general, two types of drilling are used in these diffusers. For aeroplanes with small engines of say 80–200 h.p., where no accelerating pumps are used in the carburetters and where only a small drop from maximum power gives cruising speed, a throttle curve as shown in Fig. 2 is necessary. The richness at the lower revolutions is necessary to get satisfactory acceleration, and a diffuser with a series of holes extending from top to bottom is usually indicated.

To go to the other extreme, there is the case of the relatively small military aeroplane fitted with a very powerful engine in which the object is to get off the ground rapidly and climb to great heights at very high speed. Having reached the required height the throttle can be closed quite a considerable amount compared with the former type, and some of these high powered aeroplanes will cruise comfortably on one third of their maximum power output. This calls for quite a different shape of throttle curve if economy at all cruising speeds is to be obtained, and Fig. 3 shows how the cruising range has been extended.

A diffuser for a curve of this type has two or three rows round the diffuser not far from the top, the uppermost row being approximately at the fuel level in the float chamber. This type of diffuser, in conjunction with a choke tube of the streamline type (see Fig. 4), has enabled the

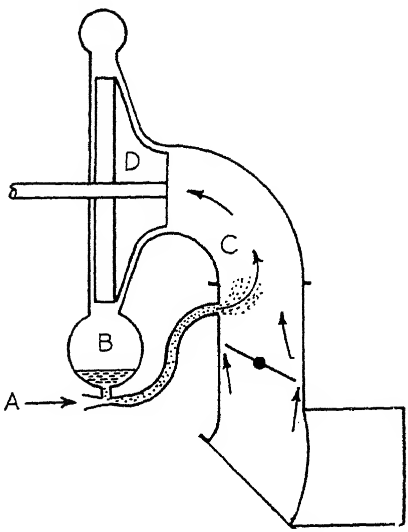


Fig. 5.—A VENTURI-DRAIN IN ACTION.

Fuel collects at B and is picked up by air entering at A, being drawn in at C and recirculated by the impeller D.

Hobson throttle curve to be brought steadily back through the cruising range as engine/aeroplane conditions called for it. With it, however, increased the difficulty of acceleration. With a small degree of flatness in the curve a single action accelerating pump was sufficient, but the steeper the curve became from the slow running point, the greater was the difficulty of ensuring acceleration under all conditions, and eventually a delayed action pump had to be incorporated in the carburetter. The action of this pump was described earlier in the section "Carburation."

If a boost control is fitted, this is, of course, adjusted to give the correct ground level induction pipe pressure, and although the throttle control lever will be fully open for normal boost, the carburetter throttle will be partly closed, depending on blower pressure, etc. This subject is dealt with exhaustively in the section devoted to Automatic Engine Controls.

As engines of the same series vary slightly it is seldom possible to time the opening of the power jet valve by a strict angular movement of the pilot's throttle lever. It is customary, therefore, to adjust it to come into action when a certain definite percentage of the maximum power is reached during dynamometer tests, the adjustment then being locked. This adjustment is now usually in the form of an external worm and wheel and is fixed by a locknut on the end of the shaft carrying the power jet cam. Earlier models had a vernier type adjustment to which access was obtained by removing a cover plate on top of the float chamber.

If, therefore, it is at any time necessary to strip the carburetter, great care must be taken to mark accurately the relative position of the cam and shaft by scribed lines, so that it can be replaced with the assurance that the power jet timing is neither too early nor too late. The throttle curve is the principal one, but others are taken and the various tests made are described at length in the section dealing with Engine Testing.

Loading up in Superchargers

This is a term applied to a gradual accumulation of fuel in the bottom of the supercharger or blower casing. When ticking over or at low engine speeds, such as during a glide, fuel often deposits on the walls of the

blower and collects in a puddle at the bottom, the air speed being insufficient to pick it up into the air stream. This can amount to a considerable quantity, and when the throttle is opened the engine is temporarily suffocated by a grossly over-rich mixture. Acceleration therefore is very bad and the engine may even stop altogether. To avoid this deposition of fuel a device known as a venturi-drain (or volute drain) is used, which sucks up the fuel as soon as it is deposited and throws it into the air stream between the carburetter throttle and the blower. The depression here is low and holds the fuel better in suspension, the rotor assisting to do this. If loading up becomes excessive it is usually due to the slow running adjustment being set needlessly rich or to flooding, and a hot air intake to the carburetter will enable steadier slow running to be obtained with less fuel consumption, while at the same time minimising loading up, both in the blower casing and the induction system.

Fig. 5 shows the layout of a venturi-drain. Usually it is mounted directly under the blower casing. Deposited fuel is drawn through a small hole drilled in the lowest point in the casing by the injector action of the venturi. Air passes continuously through the venturi from the outside atmosphere *viâ* the pipe to the point where it enters the carburetter or blower intake, taking the deposited fuel with it. The air should be taken from a source free from dirt, and is sometimes taken from the carburetter air intake. The actual size of the venturi throat is quite small (about $1\frac{1}{2}$–3 mm.), and except on small engines is unlikely to increase the slow running speed appreciably. If it does, the carburetter throttle should be allowed to close a little by means of the throttle stop screw, until the original tick-over speed is obtained. These venturi-drains are known in U.S.A. as "gurgle tubes," which rather aptly describes the sound they make when sucking up the fuel with the carburetter throttle in the tick-over position.

AERO ENGINE TESTING

By E. W. Knott, M.I.A.E., M.S.A.E.

IN order that an aero engine is tested in a manner which gives reliable results, a considerable amount of machinery and recording instruments is necessary. Aero engines have to pass stringent tests, in order to comply with Air Ministry regulations, the chief of which is the "type test," which involves many hours of running, including weak mixture test and overload test. Such a test calls for the constant attention by several people, each with their own particular duties, combining observation of the engine's performance and the recording at frequent intervals of the observed results.

The most important, and at the same time the bulkiest of the plant, is the machine for absorbing and measuring the power given out by the engine, which consists mainly of measuring torque, revolutions per minute, and fuel and oil consumption, to which must be added important incidentals, such as oil and water temperatures, cylinder temperatures, the behaviour of magnetos and sparking plugs and the efficiency of the engine under conditions which simulate take off, climbing and cruising at altitude, etc.

Power Measuring Devices—The Water Brake

Probably the best-known power measuring device is the Heenan & Froude water brake, in which the power is absorbed by the vortex action of water in a casing, which action can be controlled. Fig. 1 shows diagrammatically a section through such a water brake. It consists of a stout bedplate, securely fixed to the ground, on which is mounted on bearings a casing supplied by water under pressure. Passing through the casing is a shaft carrying a rotor of special shape, and it is to this shaft that the engine to be tested is connected. The shaft runs in roller bearings and is therefore, for all intents, frictionless. The rotor, in effect, consists of a disc mounted on the shaft, on each side of which are cups of special shape, and the aforementioned casing has corresponding cups to which an adequate supply of water is fed. Between the rotor and the casing are thin sheet slides, which can be moved in and out between the rotor and the casing such as a canal sluice gate operates. If water is supplied to the casing and the rotor shaft revolved, the turbulence created by the cups creates a hydraulic resistance, which would tend to turn the casing with the shaft if it was not restrained. This restraint can be a measure of the torque or twisting effort given to the rotor shaft by the engine, and by fixing an arm to the casing and restraining its tendency to turn the torque can be accurately measured. The pull on the end of the

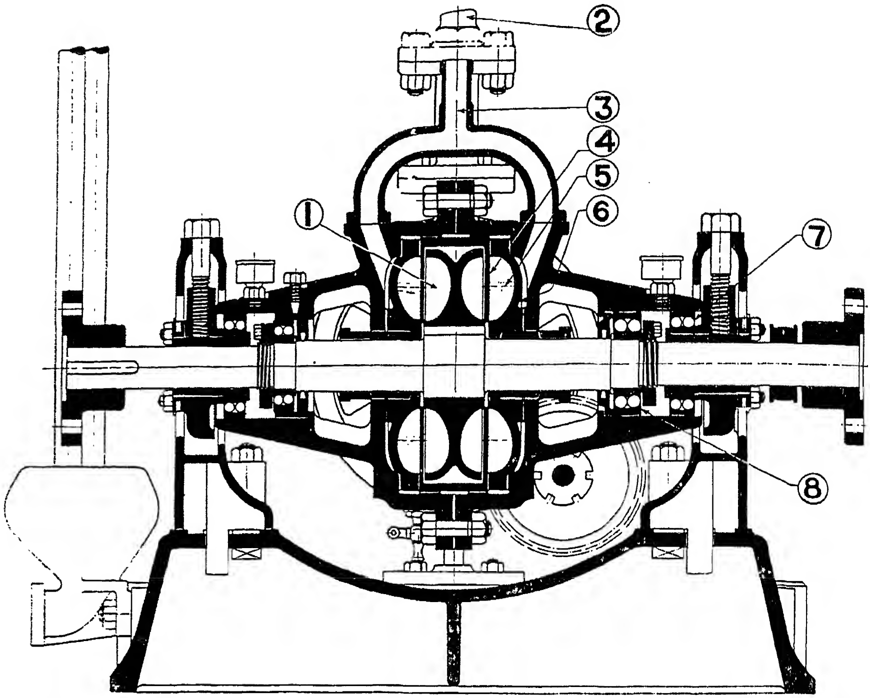


Fig. 1.—ELEVATION THROUGH CASING OF FROUDE DYNAMOMETER, TYPE D.P.X.

1. Rotor.
2. Water outlet valve.
3. Water inlet valve.
4. Sluice gates for load control.
5. Water inlet holes in vanes.
6. Casing liners.
7. Casing trunnion bearing.
8. Shaft bearing.

arm may be measured either by hanging weights on it at a fixed distance from the centre of the casing, or else by using a spring balance. It is only necessary to know the length of the arm, the pull on it and the revolutions of the rotor shaft to calculate quite easily the horse-power developed by the engine.

Although a very small amount of power is absorbed by the bearings of the water brake—or dynamometer to give it its correct name—these are all recorded on the pull measuring means and therefore introduce no errors. Only when the bearings are in bad condition and the friction varies over a large range in a spasmodic fashion will the recorded results be correspondingly erratic and therefore unreliable.

The Dynamometer

Engine tests, to be reliable, should consist of a series of observations taken under conditions where influences such as temperatures, etc., do not vary to an extent which might make the readings taken doubtful,

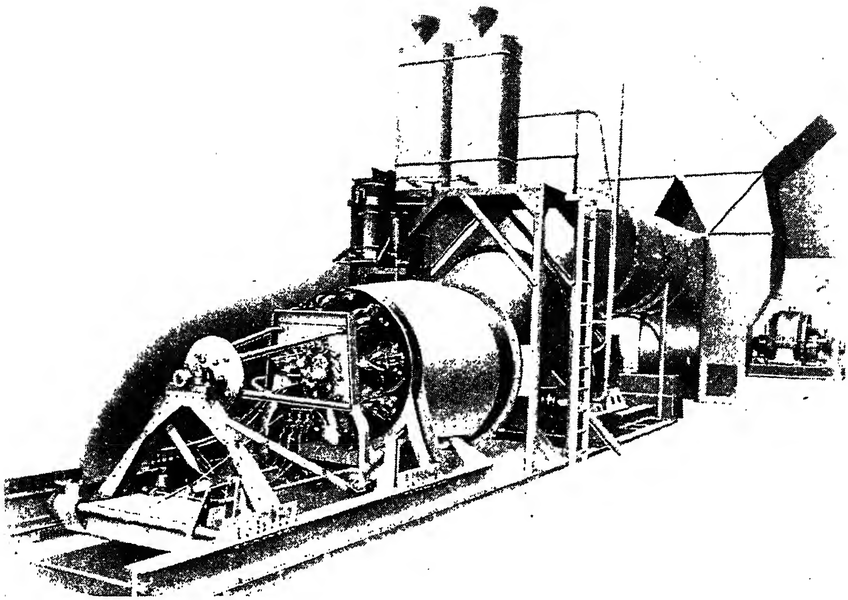


Fig. 2.—A FROUDE WIND TUNNEL TESTING PLANT.

and it is therefore essential that having nursed the engine into a condition where reliable observations may be expected, that changes in speed and torque can be made without stopping the engine between each reading. On the Heenan & Froude dynamometer, this is obtained by means of a handwheel, which when turned can alter the position of the slides between the rotor and the casing while the engine is running. Screwing the slides in relieves the load on the engine and screwing them out increases the load. In this way a wide range of torque measurements can be obtained.

The Water Supply

As the power put into the dynamometer is almost entirely absorbed by the water and the ultimate end of all power generated is heat, there will be a rise in temperature in the water circulating through the dynamometer, or "brake" as it is commonly called. The makers specify the amount of water and the pressure necessary for the maximum power absorption capacity of each size of machine, and it is advisable to have the water piping of such a size that 4 gals. per hour for each brake horsepower (b.h.p.) absorbed is assured, that the pressure does not fluctuate and that the water supply is sufficient to prevent the temperature of the water, as it leaves the brake, from exceeding a maximum of 180° F. If the water supply is inadequate, the water may boil, with the result that the hydraulic resistance is suddenly lost, causing very erratic

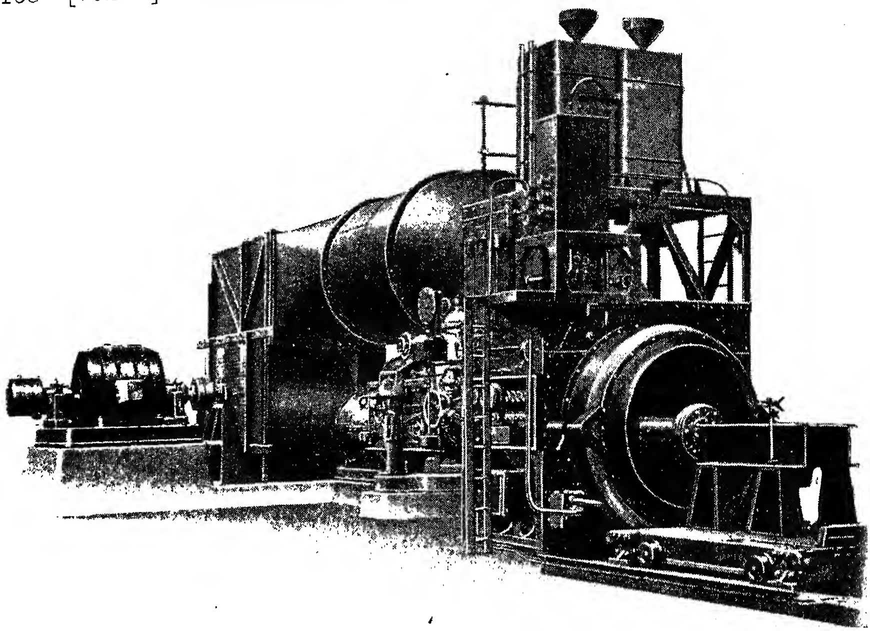


Fig. 3.—A FROUDE WIND TUNNEL TESTING PLANT.

In this case the direct current motor used for starting and running in the engine is mounted on trunnions and coupled to the same weighing gear as the Froude Dynamometer, and enables accurate measurements of motoring power to be obtained and is useful in investigating the mechanical efficiency of the engine. Note the other motor on the left used for driving the cooling fan.

readings and the certainty of the engine speed racing upwards, an event which can cause serious damage before it can be controlled. A thermometer is therefore always fitted in the water outlet of the brake and it should be very frequently observed, the water supply being controlled so that the temperature is kept within safe limits.

Brake Constant

The length of the arm on the Heenan & Froude brake is always so fixed that the calculation necessary to determine the b.h.p. is simple. It contributes to a figure known as the brake constant, which is stamped on the machine's name plate and is known as K.

If W is the weight in pounds which exactly balances the pull of the arm, and N is the r.p.m. of the rotor, then $\frac{W \times N}{K}$ gives the b.h.p. being absorbed by the brake.

Operation and Maintenance

For extreme accuracy, it is important that the arm is horizontal, and pointers and a handwheel are provided by means of which this is

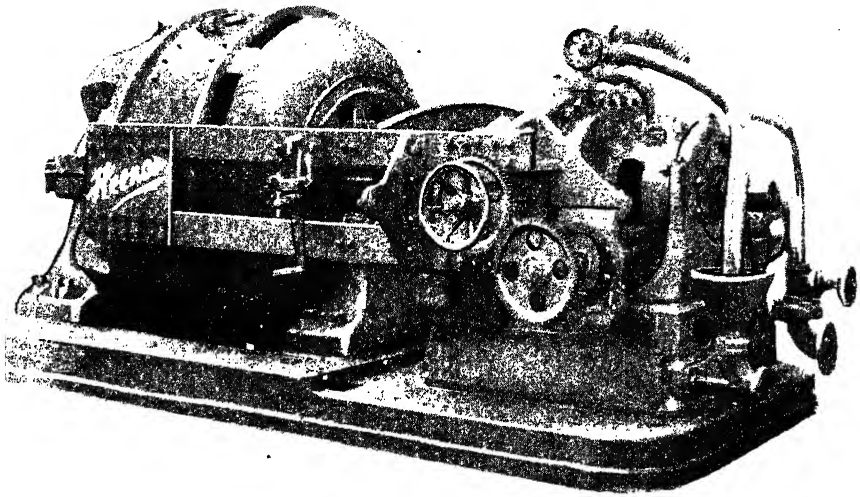


Fig. 4.—A CLOSE-UP VIEW OF A COMBINED ELECTRIC AND HYDRAULIC DYNAMOMETER. Showing the rigid connection between the two.

assured as the angular position of the arm varies with the power being absorbed by the brake, and the arm can be brought back to the correct horizontal position by turning the handwheel. Screw-down type greasers are fitted, and provided these are attended to at regular intervals and the water drained from the casing by means of the small drain cock at the bottom of the casing—should there be danger of frost or the brake is unused for a long period—no skilled attention is necessary. Only at long intervals do the packing glands require attention if water leakage is observed. A dashpot is fitted to the arm to damp out any sudden changes in torque which might damage the mechanism. This dashpot is filled with oil and its action is adjustable by means of a screw, and, provided it is kept filled with oil, need not be touched.

Cooling

While the engine is running, its temperature, whether air- or water-cooled, must be kept within certain limits. Too low a temperature will cause loss of power and too high a temperature damage through seizure of pistons and bearings. When air-cooled engines are being tested on the brake, a powerful blast of air must be directed on them, and for this purpose an electrically driven centrifugal fan is used, the air being confined to a tunnel-shaped passage, which directs it on to the engine. Means are provided for regulating the speed of the air passing the engine, so that it conforms approximately to that which the engine would have in actual flight. A wind speed measuring instrument forms part of the

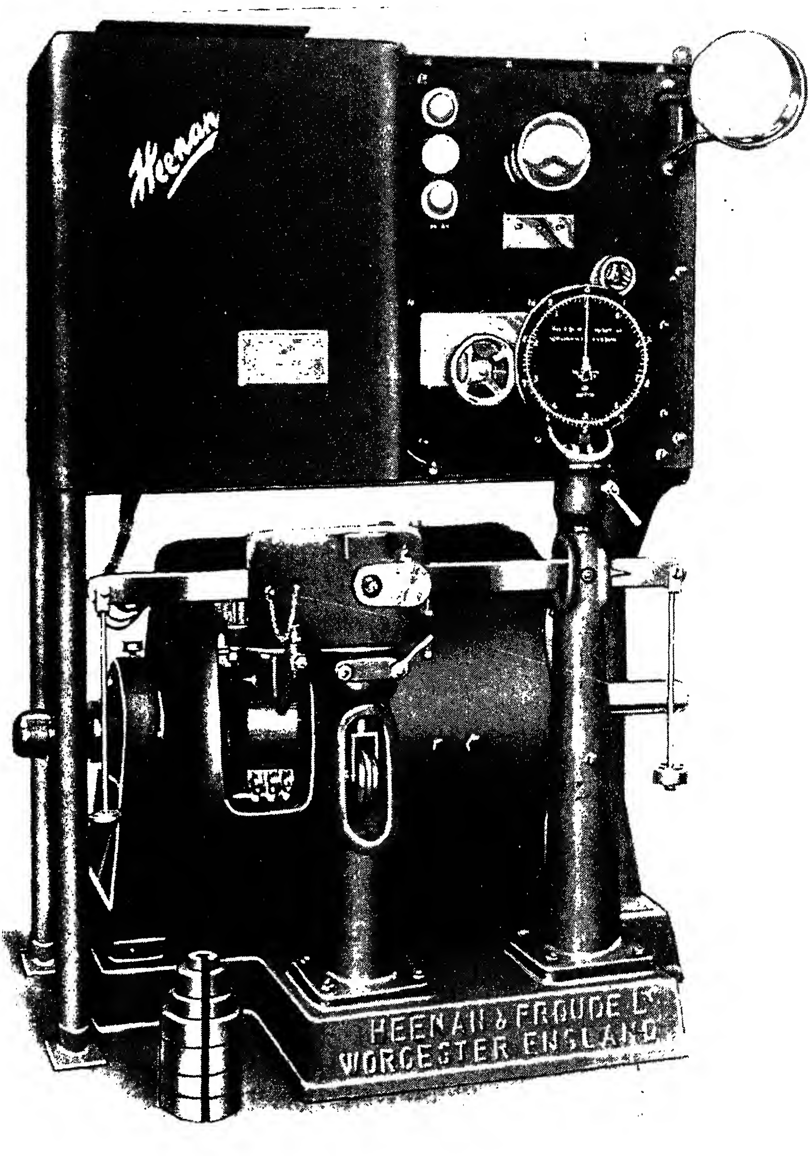


Fig. 5.—A HEENAN PATENT ELECTRIC DYNAMOMETER.

This is of a universal type, as it can be used both for production or research testing. The dynamometer carcass is mounted on trunnions and coupled to accurate "Froude" pattern torque reaction measuring gear. A large number of these have been supplied to various parts of the world.

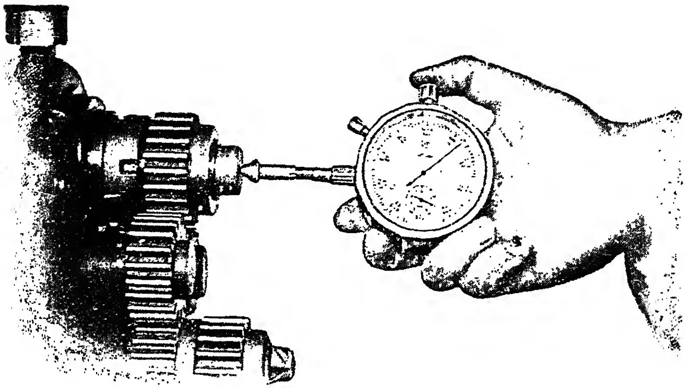


Fig. 6.—THE HASLER REVOLUTION COUNTER IN USE.

test bed equipment and the Pitot tube portion of the instrument is placed between the engine cylinders. In some installations various safety devices are installed, so that, for instance, the air blast must be started before the engine is set in motion.

A powerful electric motor forms part of the test bed and is used for starting up the engine and for the preliminary running-in after it is erected. In some cases it is arranged so that the power absorbed by friction, etc., can be measured when the engine is "motored round" at various speeds.

There are in use, in steadily increasing quantities for aero engines, electrical dynamometers. In these, the engine is coupled to a dynamo, which by means of suitable switch gear and wiring, can be converted to an electric motor driven from an independent source of supply such as the work's electrical mains. The motor is used to start up the engine, and as soon as it is running, the motor is converted to a dynamo, which generates electricity. This electricity is absorbed by adjustable resistances or fed into the work's mains. In most cases the field casting of the dynamo is mounted on bearings, an arm and a spring balance measuring the torque as with a water brake. Combined water and electric dynamometers are also made. See Figs. 3, 4 and 5 for examples of the various types.

Measurement of Speed

It is important that accurate readings can be taken of the number of revolutions per minute at which the engine is running, otherwise its horse-power cannot be calculated.

The Hasler Speed Indicator

Instruments for giving a direct reading of the speed at which the dynamometer is running are fitted to the test plant, are usually belt

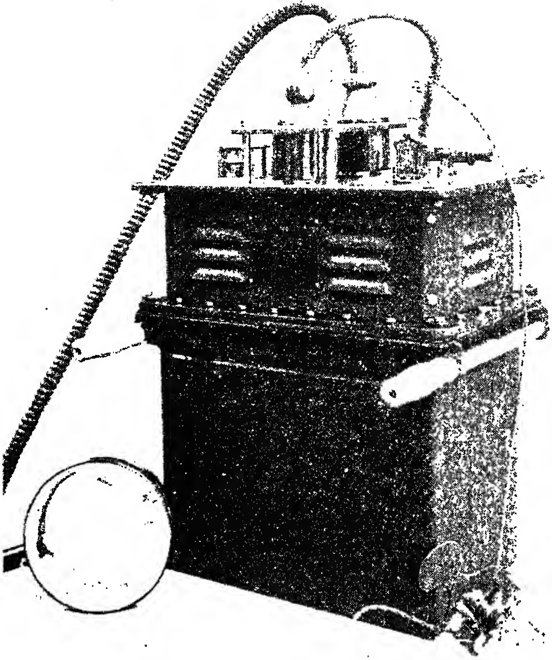


Fig. 7.—A PORTABLE MODEL OF A NEON LIGHT STROBOSCOPE KNOWN AS THE STROBORAMA.

The portable light is shown on the left and can be carried to any desired point.

driven, and are properly named tachometers. In addition, the revolution indicator normally driven by a flexible shaft from the engine, and as fitted in an aeroplane, can be used, but a check is usually taken with an independent portable instrument of the watch type. Probably the most universally used device of this nature is the Hasler. It is held in the hand and a triangular pointed steel projection is held firmly in a conical hole accurately and centrally drilled in the end of the dynamometer shaft. In addition, two other small projections or knobs, which lie conveniently to the thumb and forefinger, form part of this instrument.

The method of use is as follows :—The pointed driving spindle (which can also be fitted with a cone ended rubber tip) is pressed firmly into the recess in the end of the shaft. One knob is pressed. This winds up the recording mechanism, which is then automatically released, the pointer travelling round the dial at a rate which depends on the speed at which the shaft is revolving. It runs for about 5 seconds, 3 seconds of which is actual measuring time, and the pointer then stops. After noting the figure indicated by the pointer, it can be reset to zero by pressing the second knob. When using this or any other similar type of revolution counter, it is essential that the pointed projection is held firmly and at right angles to the end of the shaft, or slipping may take place and inaccurate readings recorded. Fig. 6 shows this instrument in use.

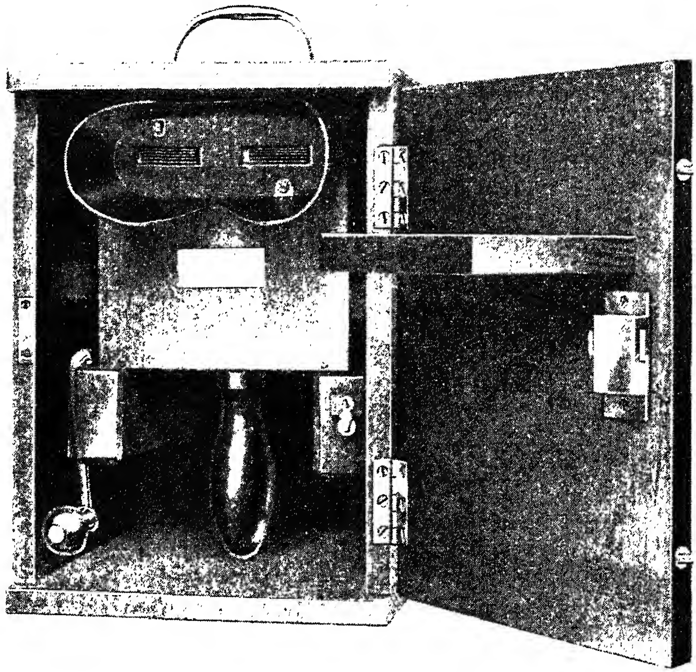


Fig. 8.—THE ASHDOWN ROTOSCOPE IN ITS CARRYING CASE.

The Stroboscope

Another method of accurately testing the speed of revolving parts is by means of an instrument known as a Stroboscope. It can also be used to examine the behaviour of rapidly moving parts, such as valve rockers, etc., it being possible to produce a stationary or slow-motion effect of the part under observation. There are two types, one in which the part to be viewed (or a mark on a revolving shaft) is seen through a shutter, which cuts off the view at very accurately timed intervals, and the other in which the engine or shaft is viewed by direct vision with the aid of a rapidly fluctuating neon light. The latter, however, requires the observed part to be preferably in a more or less subdued light, if the best results are to be obtained, and uses transformers giving very high voltage which must be efficiently "earthed" before the machine may be safely handled. The fluctuating current passing through the neon tubes can be varied in frequency by means of an electrically driven contact breaker, the motor of which is fitted with an accurately calibrated speed counter. If the frequency of the neon flashes equals the frequency of the moving part being observed, it appears to be stationary,

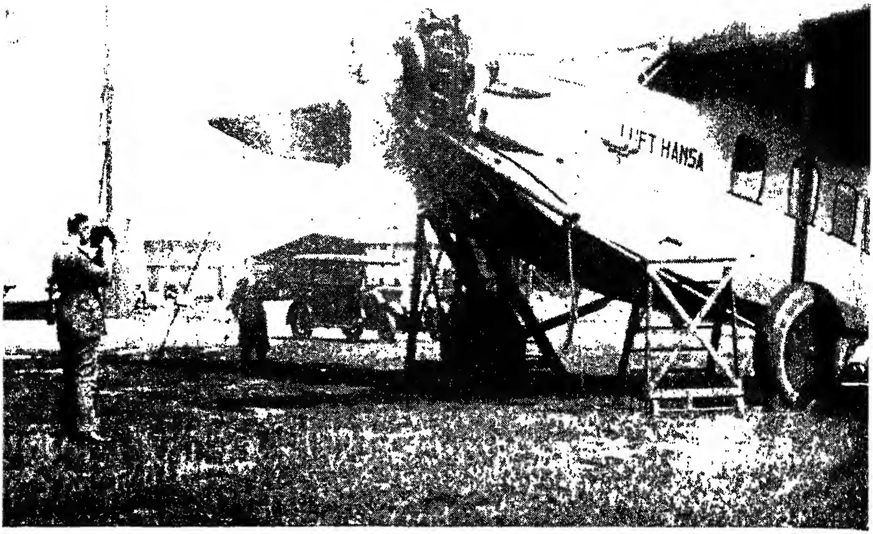


Fig. 9.—THE ROTOSCOPE BEING USED TO CHECK THE REVOLUTION COUNTER IN THE PILOT'S COCKPIT BY ACCURATE MEASUREMENT OF THE PROPELLER SPEED.

but if there is a slight difference in frequency, the part appears to be moving very slowly, which enables such phenomena as valve bounce, etc., to be checked. Actually these slow-motion pictures consist of separate consecutive views of the moving part, each view being slightly later or earlier by an equal amount from the previous one, and although the part may be travelling at a speed which makes it impossible to see with the human eye what is happening, the Stroboscope enables this to be done and has revealed many interesting and unexpected facts. See Fig. 7.

The Mechanical Stroboscope

An excellent type of mechanical Stroboscope is that known as the Ashdown Rotoscope. This depends upon the principle already referred to on page 143—the observation of moving parts of machinery through a shutter which cuts off the view at accurately timed intervals. It is portable and contains clockwork-driven mechanism, which runs at an accurately regulated speed. The "A" type instrument has a speed range of 100 to 4,000 per minute, and the "B" type instrument from 500 to 20,000 per minute.

The method of adjusting and using the Ashdown Rotoscope will next be described.

THE ASHDOWN ROTOSCOPE

On top of this instrument (see Fig. 8), is a sliding scale giving speeds in hundreds of r.p.m.; a disc on the side gives the units. The controlling disc should be set to the maximum speed, and then slowed down until the first stationary view is seen. The exact speed can then be read directly from the scales.

In order that the speed of the Rotoscope can be checked, a small lever is provided, which when moved causes the rotor to give a clicking sound, the rate of which can be checked against a stop watch. A master key is provided and can be used to raise or lower the speed of the rotor until exactly 120 clicks a minute are counted; the instrument is then correctly calibrated.

Another type of portable Stroboscope has the rotor propelled by an air blast obtained by squeezing a bulb of scent spray pattern. The faster the bulb is squeezed, the faster the rotor runs, and with a little practice, any desired steady speed can be kept up. This instrument is for inspection purposes only and cannot be used for measuring speed.

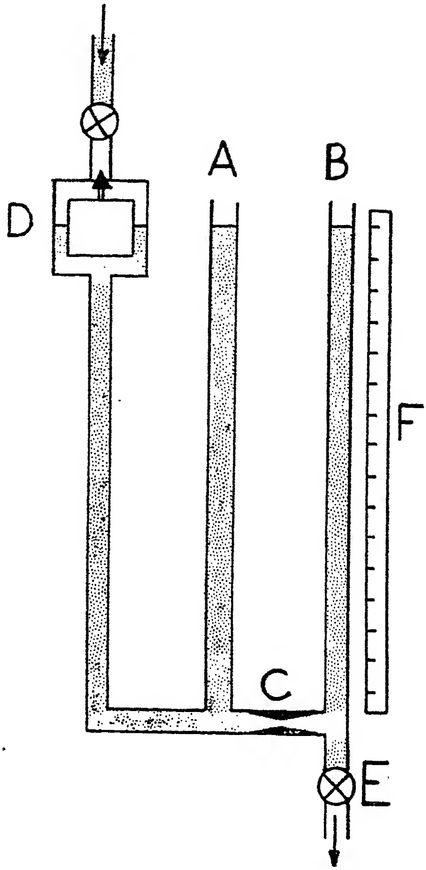


Fig. 10.—THE PRINCIPLE OF THE AMAL FUEL FLOWMETER.

Measurement of Fuel Consumption

Except in rare circumstances, measuring fuel flow by checking with a stop watch the time required to use a measured quantity of fuel is not now used. An instrument known as a flowmeter is employed and has many advantages over the old method. It is more accurate, takes less time, enables variation in carburetter flow to be seen, minimises the risk of fire and enables immediate results to be observed for changes in engine or dynamometer adjustment, and requires no calculations.

The Amal Flowmeter

Probably the best known flowmeter is the Amal, formerly called the Brown & Barlow. It is in use extensively all over the world and probably

Fig. 11.—THE AMAL FLOWMETER AS ACTUALLY CONSTRUCTED.

almost exclusively in Great Britain. Fig. 10 shows the principle on which it works. Two vertical tubes A and B are connected by a venturi passage C. A float chamber D maintains a constant level in tube A, and so long as no fuel is flowing through cock E, the level in tube B will be the same. If, however, cock E is opened and fuel flows to the carburetter, the level in tube B will drop, the amount depending on the rate at which it is flowing. By mounting a suitably marked scale beside tube B, the flow of fuel can be read. Although it is customary in this country for the scale to be marked in pints per hour, machines can also be calibrated in litres per hour, U.S.A. pints per hour, and in the case of the largest model, gallons per hour. In actual practice the machines are built with two tubes B, each with its venturi, as shown in Fig. 11. Two different scales can be used, as for instance 32 to 123 pints per hour and 100 to 390 pints per hour. Both scales may be used together, the flow being the sum of the two readings, but if this is done, a certain maximum fixed by the makers must not be exceeded. Where it is desired to test two carburetters at once, both scales may be the same and the machine can only be calibrated with both scales of the same unit of measurement.

If the instrument is to function reliably, certain rules must be obeyed.

1. It must be fixed rigidly in a vertical position.
2. A head of fuel on the float chamber must be kept between a minimum of 9 in. and a maximum of 30 in. It is, therefore, desirable to have tanks which are shallow and of large diameter, as the variation in head is not so marked as with deep narrow tanks. Where the position or size of existing fuel tanks will not permit this, an intermediate or "pressure breakdown" float chamber must be used in the pipe line from the tank to the flowmeter. It must be of ample flow capacity and fitted 9 in. above the flowmeter float chamber.
3. Piping between flowmeter and carburetter must be so laid that air-locks cannot occur or else irregular readings will be given.
4. The fuel should be well filtered.

Using the Flowmeter

The routine when commencing a test must be taken in the following order :—

1. Close the outlet cocks.
2. Turn on main fuel supply and wait until both tubes are filled to the same level.

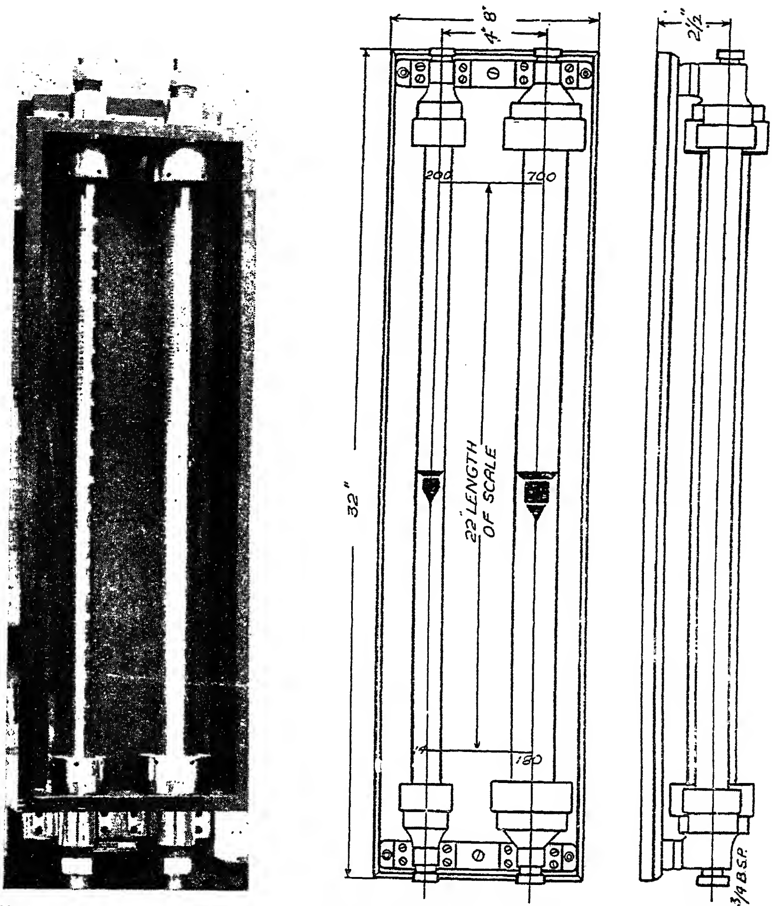


Fig. 12.—THE ROTAMETER, AN ACCURATE FORM OF FUEL MEASURING DEVICE.

3. Open the air release valves and wait until fuel runs freely from them. Then close the cocks. This is important, as if air is trapped in the instrument, false readings will be given.
4. Open the required outlet cock. As the pipes and carburetter fill up, the level in the tube will drop until they are full and then rise to the same position. As air from the piping will probably have gone up into the flowmeter, the air release valves should again be kept open until fuel flows freely, before closing them.
5. Leave the main and outlet cocks open and proceed with test. If, as the engine is speeded up, the fuel level starts to drop below the bottom reading of the scale, turn on the other tap,

for readings should not be estimated outside the extreme markings on the scale, and if the fuel level disappears from sight, air may get into the instrument.

Maintenance

Periodically and especially if the fuel is not well filtered, each venturi should be unscrewed and cleaned with a piece of rag dipped in petrol, as any deposit of foreign matter here will cause the instrument to indicate flows that are higher than are actually the case. On no account must wire be used, as the size and shape of the hole is of extreme importance. Flush out the machine with petrol and replace the venturi.

As the machine is of different construction to a jet calibrating machine, although very similar in appearance, no attempt should be made to use it for calibrating the size of a jet, as the results will be incorrect.

The Rotameter

This is another form of fuel flow measuring device and is notable for its extreme simplicity. It consists of a tapered transparent tube, in which the bore is largest at the top. In it is a float of special shape. It is circular in section, pointed at the bottom and has a cone-shaped ridge at the top. Fuel enters at the bottom of the tube and leaves at the top. It has to pass between the coned top of the float and the tube, with the result that the faster it flows, the higher up the tube the float must be to give the necessary area. A graduated scale beside the tube enables the rate of flow to be measured.

The top rim of the float is constructed so that it spins continuously while fuel is passing and readings are taken at the level of the top of the float. This spinning action keeps the float always in the centre of the tube, so that errors due to friction between the two are avoided. If the float fails to spin, it is a sign that the tube is not vertical or that the float requires cleaning. At the same time, the tube should be cleaned, a light bristle brush on a long wire handle being the best medium for this purpose.

The tubes are held at both ends in packing glands, to which unions are fitted for connecting the inlet and outlet pipes. Extreme care must be taken not to strain the instrument when connecting these pipes, or the tubes may be broken. Flexible connections close to the instrument are recommended at both top and bottom, as these eliminate risk of damage due to vibration, mechanical strain or expansion and contraction, which may occur in rigid piping.

Where fuel consumption is required to be measured in an aeroplane in flight, in which it may not be possible to keep the Rotameter strictly vertical, a special model is available in which a fine wire runs up the centre of the tube through the float. The central hole in the float is so formed as to have a minimum bearing surface on the wire and is thereby kept

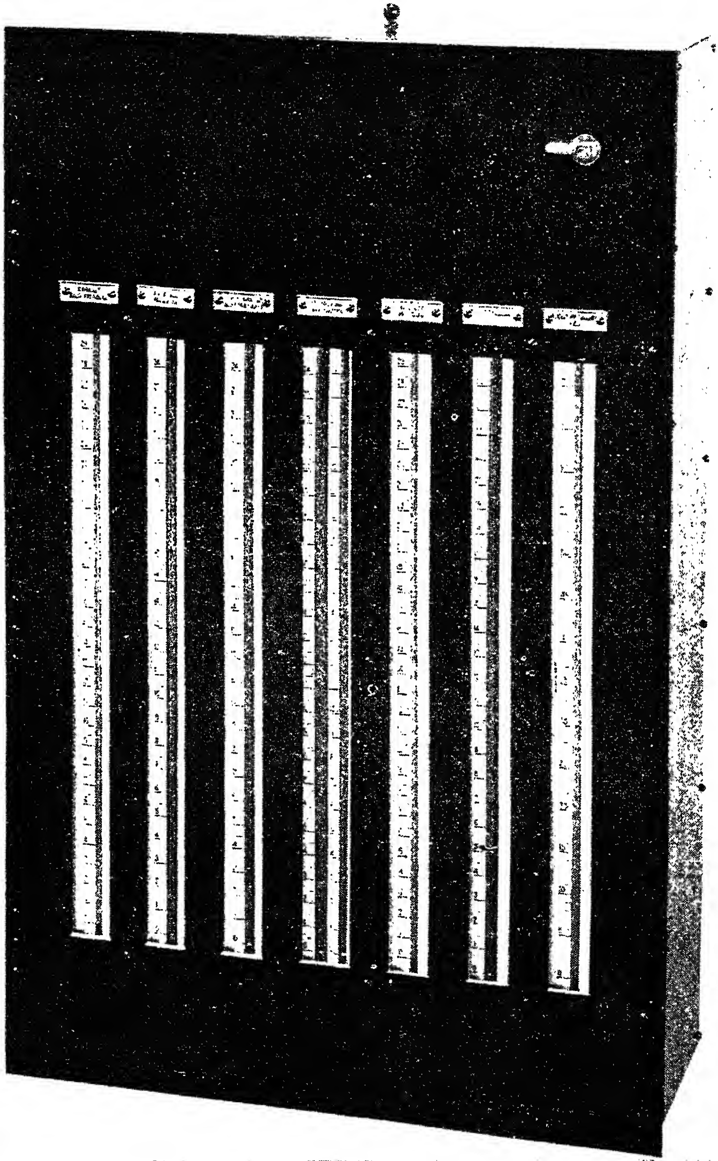
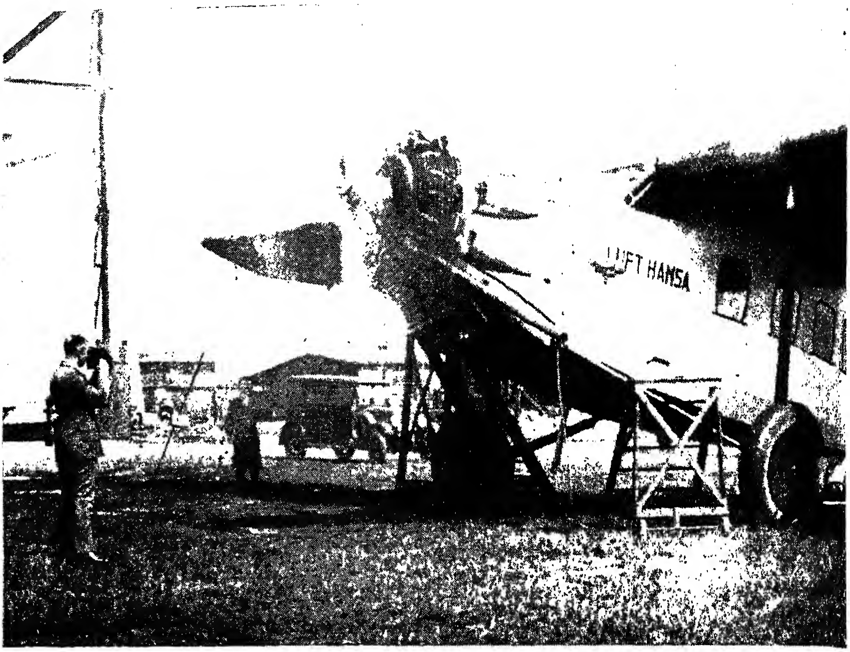


Fig. 13.—A NEST OF HOBSON TEST BED GAUGES.

These record the following readings: Exhaust Back Pressure, Air Intake Pressure, Fuel Pump Pressure, Air Blast Pressure, Boost Pressure in Inches of Mercury, Boost Pressure in Inches of Water, Supercharger Inlet Pressure.



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On top of this instrument (see Fig. 8), is a sliding scale giving speeds in hundreds of r.p.m.; a disc on the side gives the units. The controlling disc should be set to the maximum speed, and then slowed down until the first stationary view is seen. The exact speed can then be read directly from the scales.

In order that the speed of the Rotoscope can be checked, a small lever is provided, which when moved causes the rotor to give a clicking sound, the rate of which can be checked against a stop watch. A master key is provided and can be used to raise or lower the speed of the rotor until exactly 120 clicks a minute are counted; the instrument is then correctly calibrated.

Another type of portable Stroboscope has the rotor propelled by an air blast obtained by squeezing a bulb of scent spray pattern. The faster the bulb is squeezed, the faster the rotor runs, and with a little practice, any desired steady speed can be kept up. This instrument is for inspection purposes only and cannot be used for measuring speed.

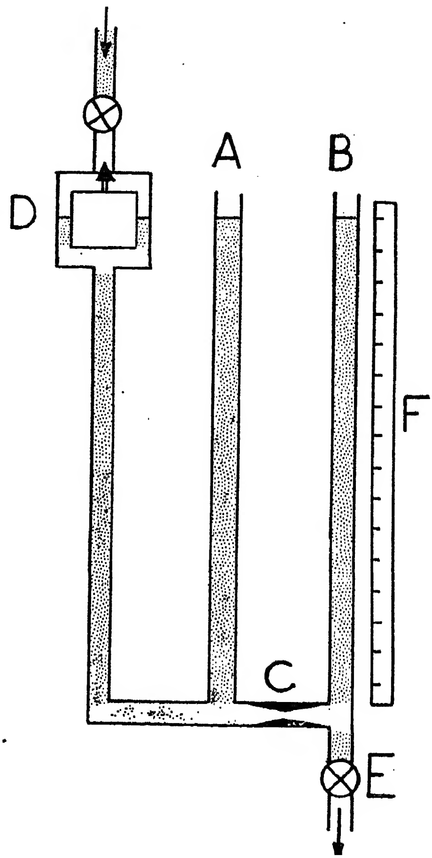


Fig. 10.—THE PRINCIPLE OF THE AMAL FUEL FLOWMETER.

Measurement of Fuel Consumption

Except in rare circumstances, measuring fuel flow by checking with a stop watch the time required to use a measured quantity of fuel is not now used. An instrument known as a flowmeter is employed and has many advantages over the old method. It is more accurate, takes less time, enables variation in carburetter flow to be seen, minimises the risk of fire and enables immediate results to be observed for changes in engine or dynamometer adjustment, and requires no calculations.

The Amal Flowmeter

Probably the best known flowmeter is the Amal, formerly called the Brown & Barlow. It is in use extensively all over the world and probably

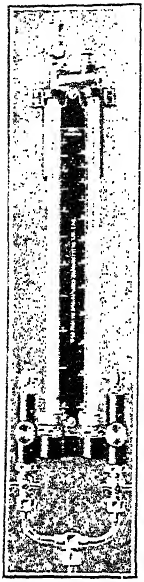


Fig. 11.—The Amal Flowmeter as actually constructed.

almost exclusively in Great Britain. Fig. 10 shows the principle on which it works. Two vertical tubes A and B are connected by a venturi passage C. A float chamber D maintains a constant level in tube A, and so long as no fuel is flowing through cock E, the level in tube B will be the same. If, however, cock E is opened and fuel flows to the carburetter, the level in tube B will drop, the amount depending on the rate at which it is flowing. By mounting a suitably marked scale beside tube B, the flow of fuel can be read. Although it is customary in this country for the scale to be marked in pints per hour, machines can also be calibrated in litres per hour, U.S.A. pints per hour, and in the case of the largest model, gallons per hour. In actual practice the machines are built with two tubes B, each with its venturi, as shown in Fig. 11. Two different scales can be used, as for instance 32 to 123 pints per hour and 100 to 390 pints per hour. Both scales may be used together, the flow being the sum of the two readings, but if this is done, a certain maximum fixed by the makers must not be exceeded. Where it is desired to test two carburetters at once, both scales may be the same and the machine can only be calibrated with both scales of the same unit of measurement.

If the instrument is to function reliably, certain rules must be obeyed.

1. It must be fixed rigidly in a vertical position.
2. A head of fuel on the float chamber must be kept between a minimum of 9 in. and a maximum of 30 in. It is, therefore, desirable to have tanks which are shallow and of large diameter, as the variation in head is not so marked as with deep narrow tanks. Where the position or size of existing fuel tanks will not permit this, an intermediate or "pressure breakdown" float chamber must be used in the pipe line from the tank to the flowmeter. It must be of ample flow capacity and fitted 9 in. above the flowmeter float chamber.
3. Piping between flowmeter and carburetter must be so laid that air-locks cannot occur or else irregular readings will be given.
4. The fuel should be well filtered.

Using the Flowmeter

The routine when commencing a test must be taken in the following order :—

1. Close the outlet cocks.
2. Turn on main fuel supply and wait until both tubes are filled to the same level.

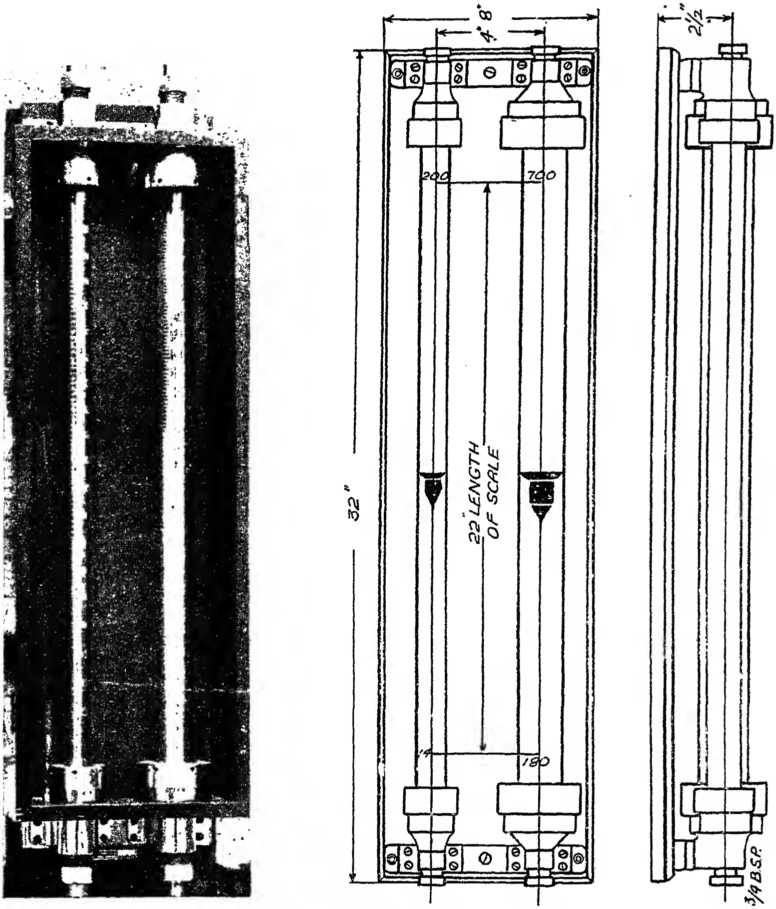


Fig. 12.—THE ROTAMETER, AN ACCURATE FORM OF FUEL MEASURING DEVICE.

3. Open the air release valves and wait until fuel runs freely from them. Then close the cocks. This is important, as if air is trapped in the instrument, false readings will be given.
4. Open the required outlet cock. As the pipes and carburetter fill up, the level in the tube will drop until they are full and then rise to the same position. As air from the piping will probably have gone up into the flowmeter, the air release valves should again be kept open until fuel flows freely, before closing them.
5. Leave the main and outlet cocks open and proceed with test. If, as the engine is speeded up, the fuel level starts to drop below the bottom reading of the scale, turn on the other tap,

for readings should not be estimated outside the extreme markings on the scale, and if the fuel level disappears from sight, air may get into the instrument.

Maintenance

Periodically and especially if the fuel is not well filtered, each venturi should be unscrewed and cleaned with a piece of rag dipped in petrol, as any deposit of foreign matter here will cause the instrument to indicate flows that are higher than are actually the case. On no account must wire be used, as the size and shape of the hole is of extreme importance. Flush out the machine with petrol and replace the venturi.

As the machine is of different construction to a jet calibrating machine, although very similar in appearance, no attempt should be made to use it for calibrating the size of a jet, as the results will be incorrect.

The Rotameter

This is another form of fuel flow measuring device and is notable for its extreme simplicity. It consists of a tapered transparent tube, in which the bore is largest at the top. In it is a float of special shape. It is circular in section, pointed at the bottom and has a cone-shaped ridge at the top. Fuel enters at the bottom of the tube and leaves at the top. It has to pass between the coned top of the float and the tube, with the result that the faster it flows, the higher up the tube the float must be to give the necessary area. A graduated scale beside the tube enables the rate of flow to be measured.

The top rim of the float is constructed so that it spins continuously while fuel is passing and readings are taken at the level of the top of the float. This spinning action keeps the float always in the centre of the tube, so that errors due to friction between the two are avoided. If the float fails to spin, it is a sign that the tube is not vertical or that the float requires cleaning. At the same time, the tube should be cleaned, a light bristle brush on a long wire handle being the best medium for this purpose.

The tubes are held at both ends in packing glands, to which unions are fitted for connecting the inlet and outlet pipes. Extreme care must be taken not to strain the instrument when connecting these pipes, or the tubes may be broken. Flexible connections close to the instrument are recommended at both top and bottom, as these eliminate risk of damage due to vibration, mechanical strain or expansion and contraction, which may occur in rigid piping.

Where fuel consumption is required to be measured in an aeroplane in flight, in which it may not be possible to keep the Rotameter strictly vertical, a special model is available in which a fine wire runs up the centre of the tube through the float. The central hole in the float is so formed as to have a minimum bearing surface on the wire and is thereby kept

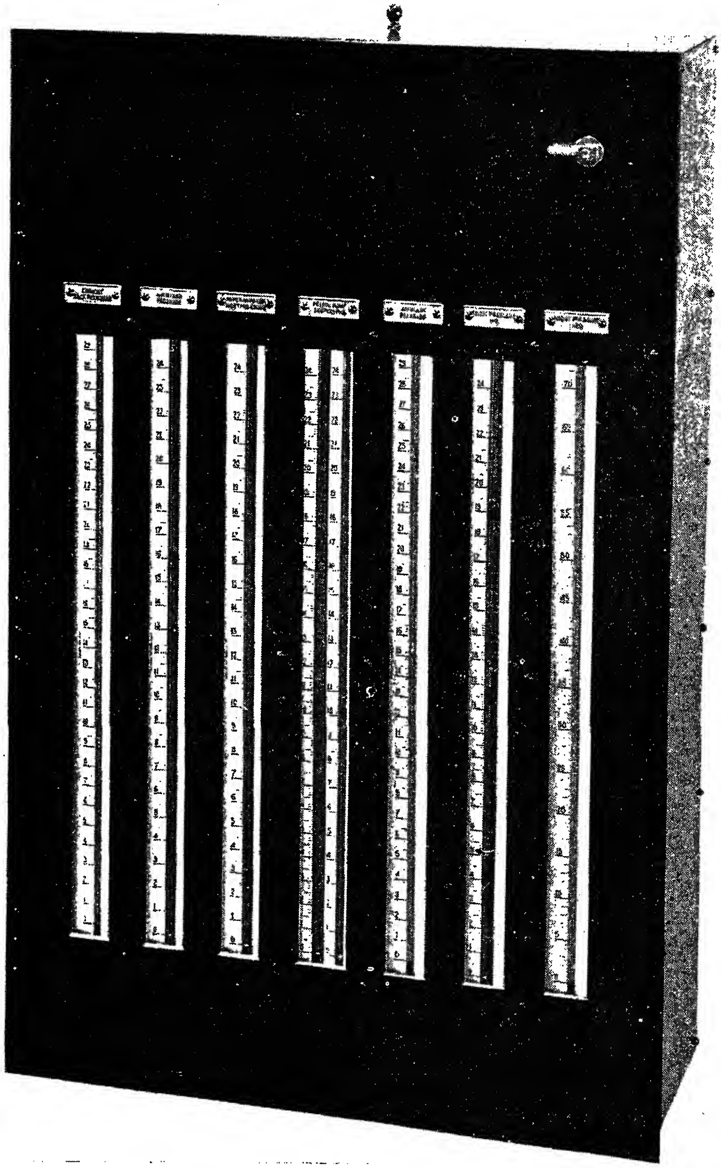


Fig. 13.—A NEST OF HOBSON TEST BED GAUGES.

These record the following readings: Exhaust Back Pressure, Air Intake Pressure, Fuel Pump Pressure, Air Blast Pressure, Boost Pressure in Inches of Mercury, Boost Pressure in Inches of Water, Supercharger Inlet Pressure.

central in the tube, even if the machine tilts a few degrees in any direction.

When using the Rotameter, it is most important that the fuel is turned *on* and *off* slowly, or the float will be driven violently towards the end of the tube.

Measurement by Weight

A third method only occasionally used is that of timing the consumption of a given weight of fuel. A fuel container is placed on one side of a pair of scales and the quantity of fuel in it exactly balanced by an assortment of weights, including one equal to the weight of fuel to be tested, say 1 lb. The container is connected by a length of pipe, which must be flexible, to the carburetter, and by means of a 3-way cock, an alternative source of fuel supply enables the engine to run on either the fuel in the container or from the other source. The engine is brought up to required running conditions on the alternative supply, and then as the 3-way cock is turned, a stop watch is started and the 1 lb. weight removed. The side carrying the fuel container, of course, drops and the scales must be carefully watched, for as soon as 1 lb. weight of fuel is consumed, the container side will rise and the stop watch must be "clicked" exactly as the indicating pointer on the scales passes the "level" mark. The 3-way cock is then turned so that the container is isolated and the engine runs once more on the other supply. In all such tests it is essential that the engine speed, load and temperatures are constant while the test is being taken.

In view of the fact that if the specific gravity of the fuel being used is taken with a hydrometer, the volume readings shown on flowmeters can readily be converted to weight readings, and undoubtedly they are simpler and quicker to use.

Measurement of Oil Consumption

A tank with a calibrated gauge glass is necessary and more accurate readings can be taken if the tank is high in proportion to its diameter. Electrical immersion heaters or steam-heated coils are necessary, so that the warming up period of the engine can be greatly reduced. On the other hand, when the engine is running the temperature of the oil has to be kept from exceeding a certain specified temperature and therefore water-cooled coils in the tank are also necessary, the various control cocks being within easy reach of the tester. When the oil temperature has remained at a steady figure for a short time, the level in the gauge glass is noted and the engine opened up to the speed at which it is desired to test oil consumption. After a minimum measurable quantity of oil has been consumed or a definite period of time has elapsed, during which the engine r.p.m. must remain constant, the engine is shut down, and after allowing a minute or two for the oil level to settle, the amount used can be read.

Measurement by Weight

The amount of oil consumed can also be measured by a method similar to that of weighing fuel on a pair of scales. The oil container complete with heating and cooling devices is mounted on one side of a large pair of scales, flexible connections being used to avoid incorrect readings. Before starting the test—but after the engine is warmed up—the container and its contents are carefully weighed and at the completion of the test again weighed, the difference giving the weight of oil used for a timed period.

Oil Temperatures and Pressures

The accurate recording of these is very important and distant reading instruments are used. In the case of oil pressure indicators the best and safest type are those in which the engine oil does not directly operate the recording instrument. With such instruments, the oil pressure affects a capsule or bellows connected by a thin tubing to the recording dial. The bellows, tubing and recording instrument are filled with a special fluid which transmits the pressure exerted on the bellows. The advantages of such a scheme are that if the bellows breaks, hot engine oil under pressure cannot be lost, and due to the nature of the transmitting fluid, immediate readings can be taken whether hot or cold.

Most of these gauges have a dial reading up to 150 lbs. per square inch, but as the pressure when a cold engine is started may exceed twice this figure, the instrument must be capable of standing a heavy overload without damage or permanent derangement of its recorded readings.

Two instruments of the remote reading type are also used, one for the inlet temperature and one for the outlet, the former usually having a range of 0–100° C. and the latter 0–150° C., although these figures are rarely reached. These consist of a bulb placed at the point where it is necessary to measure the oil temperature, a fine tube connecting it to the recording instrument. When choosing a position for the bulb, care must be taken that it is actually in the oil stream and not in an air-pocket and that the bulb does not restrict the normal flow of oil.

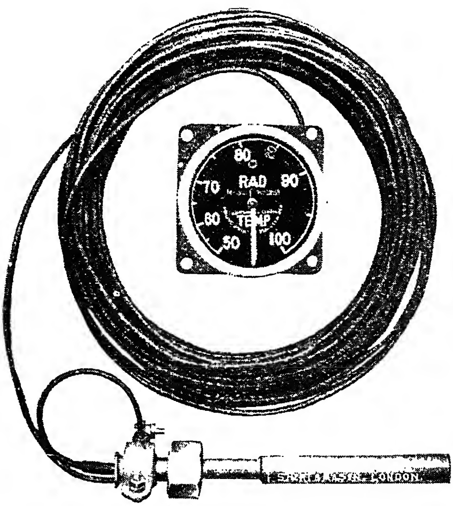


Fig. 14.—SHORT AND MASON DISTANCE READING TEMPERATURE INDICATOR.

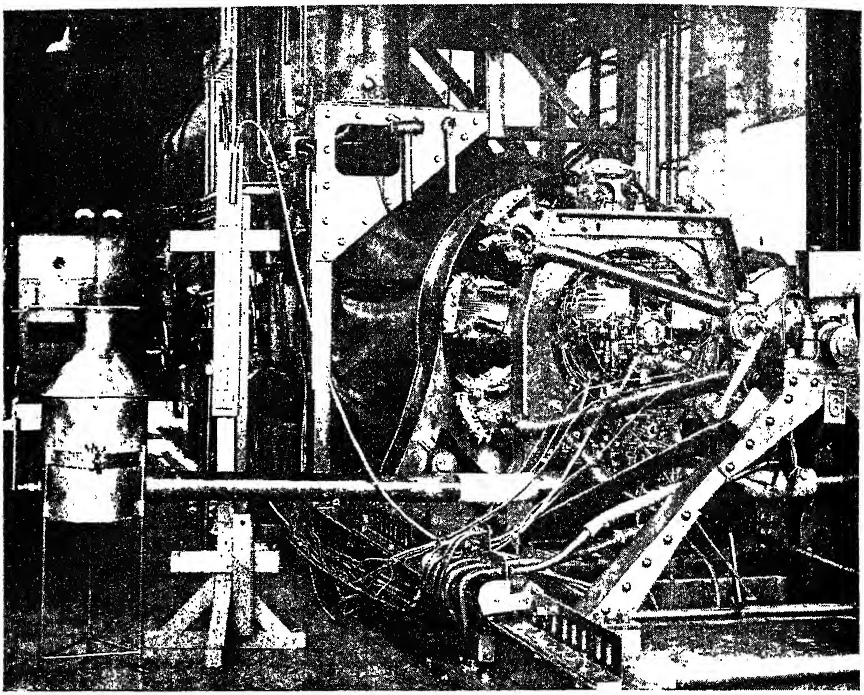


Fig. 15.—AN ALTITUDE BOX AS USED BY THE BRISTOL AEROPLANE CO. Two are used, one on each side of the engine.

Unsupercharged and Supercharged Engines

The testing of unsupercharged (naturally aspirated) engines is relatively simple compared with that of supercharged engines. With the latter, pressure gauges are necessary for recording the inlet and outlet pressures of the supercharger or blower, as it is commonly called, or of the non-geared paddle-fan or impeller type. In addition an altitude box is required, by means of which rarefication of the air supply to the engine at various altitudes can be simulated on the test bed.

Blower or induction pipe pressures may be taken by dial type instruments, but the height of a column of mercury in a glass tube is usually taken at the same time as the most reliable check. In some installations an adjustable sliding scale beside the tube enables the readings to be corrected from time to time in accordance with variation in barometric pressure, which in some parts of the world can vary considerably in even an hour or two.

The altitude depression box usually consists of a large cylindrical drum connected to the carburettor air intake, usually with a flexible, but airtight connection, and having an opening or openings which can

be infinitely varied in area. In some cases these consist of interchangeable discs having varying-sized holes and in others movable slides operated by a handwheel and screw. A connection from this box to a mercury U tube enables the drop in pressure in the box to be recorded and thereby the corresponding altitude, and as any leakage between the box and the U tube would give false readings, the utmost care must be taken that no bad joints of any kind are present.

The U tube must be made of specially selected glass, otherwise it is attacked by the mercury and the inside becomes covered with sludge. Means must be provided so that any sudden change in pressure or depression (suction) cannot draw the mercury out of the glass into the engine (this applies particularly to U tubes connected to the induction pipe) and special depression gauges are made with traps which prevent this. In addition, as pulsations may occur, some means such as an adjustable clip on one of the rubber connections should be fitted to damp these out. The induction pipe pressure in a supercharged engine is known as the "boost pressure" and is measured at a point in the blower outlet casing which is found by experiment to be most free from fluctuation. As backfires might damage the boost pressure gauge, the connecting pipe union has a small orifice to counteract such possible damage.

CHECKING MIXTURE STRENGTH BY EXHAUST GAS EXAMINATION

While the readings given by a flowmeter indicate the total fuel used by the engine for a given power output, it does not indicate whether some cylinders are getting more or less than their proper share and only an analysis of the exhaust gas taken from each individual cylinder can show this. In addition relative mixture strengths of the different cylinders often change with engine speed, and a cylinder getting an unnecessarily rich mixture at say 1,500 r.p.m. may be found to be weak at 2,000 r.p.m. due to peculiarities in the induction system.

An examination may be made two ways, by a chemical analysis of a sample of exhaust gas taken from each cylinder, which, while accurate, is a fairly lengthy job, or a fairly accurate method—comparative as between different cylinders—that is obtained by electrical devices, the underlying principle of which is the change in resistance of an electrically heated wire placed in the path of the exhaust gas. According to the variation in the constituents of the gas, so the resistance of the wire varies, and the variation is shown on a dial which can be calibrated to show a scale of mixtures ranging from too rich to too weak. Such instruments are the Moto-Vita and the Cambridge exhaust-gas tester. An illustration of the recording instrument of the latter is given. Such instruments are of real use for test bench work and on civil airliners and have found favour in U.S.A. for the latter ; but for military aeroplanes, especially in wartime, would not be of much use as they could not be given the neces-

Fig. 16 (*left*).—CAMBRIDGE EXHAUST GAS INDICATOR SHOWING RECORDING INSTRUMENT.

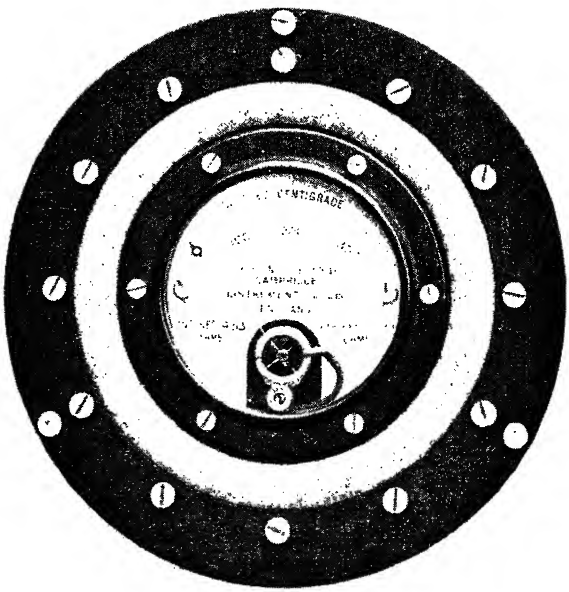


Fig. 17 (*right*).—CAMBRIDGE RECORDING INSTRUMENT FOR USE WITH THERMO-COUPLES.

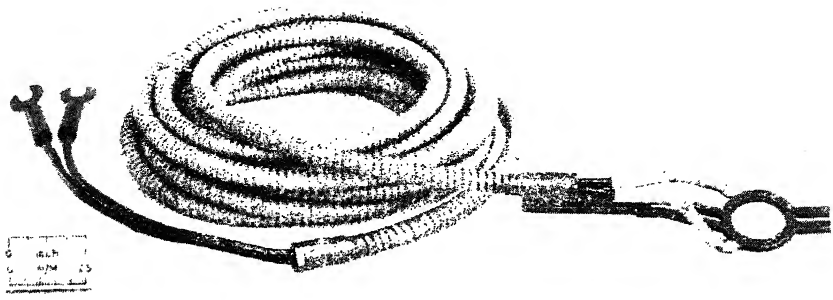


Fig. 18.—CAMBRIDGE SPARKING PLUG THERMO-COUPLE.

sary attention. With open exhaust pipes (short stubs) the colour of the exhaust flame is some indication of mixture strength, but requires a more or less darkened room. The correct flame should have a short blue cone similar to the flame of a well-regulated Bunsen burner. Long ragged blue flames indicate a rich mixture, and if black smoke is present, an overrich mixture. Short green flames ranging to yellow with a red centre indicate weak mixture, while sparks or puffs of smoke blown from the exhaust may indicate detonation, but cannot be accepted as certain unless other symptoms are present. Back pressure in the exhaust system can cause or accelerate detonation. When watching exhaust flames as a means of estimating mixture strength, one should turn towards the flames for not more than a second or two and then turn away before the eyes get confused. If the flames are stared at for some time it is impossible to make a true comparison.

Measurement of Cylinder Temperatures

These are taken at various points by means of thermo-couples. The latter consists of a junction of two dissimilar metals which, when heated, generate an electric current which while very weak can be accurately measured. The hotter the junction the greater the output of electricity, and the measuring instrument can be calibrated to read the temperature to which the thermo-couple is subjected. They are made in two forms, one similar to a sparking-plug washer, and the other of ring shape but rather larger, and known as a thimble, which is bolted to a flat place on the cylinder, specially machined for the purpose. Two insulated wires are attached to the thermo-couples and are connected to the recording instrument, and as the length and therefore the electrical resistance of the leads affects the reading of the instrument, the leads must never be lengthened, shortened or exchanged. Actually the instrument compares

the temperature of the thermo-couple with another, known as a cold junction, which, for example, can be kept in a thermos flask filled with ice and water or oil, the temperature of which can be taken with an ordinary thermometer. A calibration chart is supplied with each instrument and set of thermo-couples. The reading on the dial is compared with a corresponding temperature reading on the chart, and to this must be added the temperature of the cold junction to obtain the true temperature of the thermo-couple on the engine.

By means of a thermo-couple on each cylinder and a selective switch, readings of all cylinders in turn can be rapidly taken. Fig. 18 shows a thermo-couple of the sparking-plug washer type for use in engine testing.

The condition of the sparking plugs is sometimes an indication of cylinder temperatures and to some extent mixture strengths if excessively weak or rich. If sparking-plug trouble is suspected during a test, each magneto should be switched off in turn, when the drop in r.p.m. should not exceed 5 per cent. If little or no drop occurs, excessive advance of the ignition timing may be suspected. Different types of sparking plugs should be tested, as it is an Air Ministry requirement that two different types of plug are allocated as suitable for each make of engine. Between runs the plugs should be examined for damaged points or insulation and tested under a pressure of at least 100 lbs. per square inch. Care must be taken that the plug is free of fuel in case an explosion takes place when the hand magneto of the testing machine is turned.

THE VARIABLE-PITCH AIRSCREW

By Flight-Lieutenant J. W. Bell, D.S.M.
Service Manager, Airscrew Division, de Havilland Aircraft Co.

UNLIKE the marine propeller, which applies a steady power to the movement of a constant load, the airscrew is required to work in three dimensions in a medium whose varying density has the effect of varying the power of the engine whilst the load on the airscrew, and therefore on the engine, changes with every change of attitude of the aeroplane.

In the main these conditions are opposed one to the other, and it is impossible, therefore, to design a fixed-pitch airscrew for a maximum of efficiency in horizontal flight which will be equally efficient in climb, or one which will take off the ground the heaviest safe load which the engine power available is capable of lifting, and then transport that load from point to point in the shortest possible time.

Why a Variable Pitch is Desirable

In brief, the fixed-pitch airscrew can only be designed to operate with a maximum of efficiency for a single set of flight conditions, and it is necessary, therefore, to adopt a compromise in order to ensure a safe take-off and at the same time to secure a reasonable performance in flight.

To meet these requirements it is usual to overpitch the airscrew as much as safety considerations will admit for take-off, with result that the engine revolutions at full throttle are held down and the engine cannot deliver the full power of which it is capable at a time when it is most required.

At altitude, on the other hand, the concessions in blade pitch which have been made to ensure a safe take-off, result in an airscrew which cannot absorb the rated power of the engine at its normal rate of revolution and it is necessary to throttle back in order to prevent over-speeding of the engine, so sacrificing a considerable margin of speed in horizontal flight.

Efficiency Losses with Fixed-Pitch Airscrews

It follows that in neither of these two most important conditions of flight is the airscrew using to the best advantage the power of which the engine is capable—indeed, in the large majority of cases, the combined efficiency of the engine and airscrew is as low as 60 per cent. or even less at take-off, whilst in level flight the loss in performance, though less than the above, is still considerable.

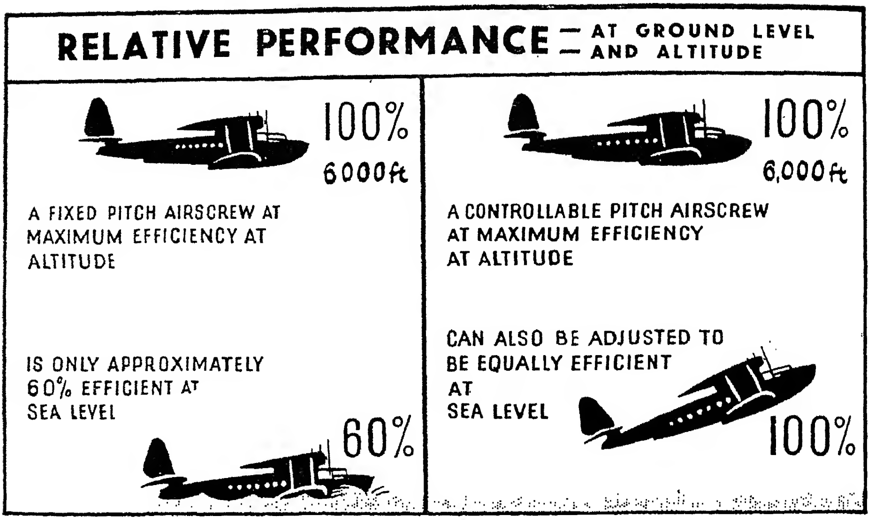


Fig. 1.—RELATIVE PERFORMANCE AT GROUND LEVEL AND ALTITUDE.

Racing and High-Speed Aeroplanes

These limitations of the fixed-pitch airscrew become an increasingly serious problem in the case of aeroplanes designed for high speed and racing; aeroplanes fitted with such airscrews are often quite hazardous to take off the ground.

A Practical Solution

It was not until quite recent times that a variable-pitch airscrew, with commercial possibilities, was produced by the Hamilton Standard Propeller Company of America.

In this, as in other designs, the airscrew has alternative pitches for climb and level flight. The blades are adjustable in both high and low pitch positions, thus enabling the aeroplane to cope with those special and usually temporary requirements of take-off, climb and speed in level flight, which occur from time to time.

The conditions of take-off, for instance, from sea-level and an aerodrome at an altitude of 6,000 ft., are very different, and an aeroplane loaded to capacity at sea-level would be quite unable to get off the ground with the same load at 6,000 ft., if fitted with a fixed-pitch airscrew.

With a controllable-pitch airscrew, on the other hand, an easily effected adjustment at the low-pitch end of the scale would enable the engine to develop its maximum horse power for take-off in either of these cases, without interference with the high-pitch setting which remains set at the most efficient angle for flying at rated altitude.

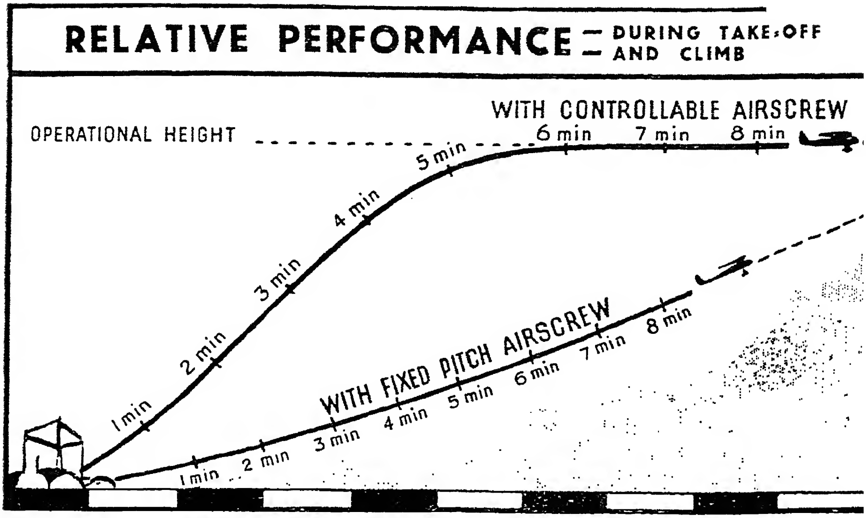


Fig. 2.—RELATIVE PERFORMANCE DURING TAKE-OFF AND CLIMB.

Use when Developing Aeroplanes

A further advantage is conferred by the controllable-pitch airscrew in that it can be varied through a relatively wide range of pitch angles to conform with development in the aeroplane or alteration in engine power. It thereby obviates the need for a series of development airscrews, whilst often it will be found that the controllable-pitch airscrew can be used on kindred types without loss of efficiency.

In brief, the controllable-pitch airscrew possesses an adaptability, unknown to the fixed-pitch airscrew, which enables heavier loads to be taken out of smaller aerodromes than formerly, and these loads are taken to altitude and transported from point to point in much less time and at lower cost than has been possible hitherto, whilst the rate of wear and tear of the engine is substantially reduced.

General Description of V.P. Airscrew

In principle the design of all variable-pitch airscrews is similar—they all provide rigid blades which are rotated about their centre lines in order to change pitch. An outer member called the barrel envelops the blade roots and is designed to absorb the centrifugal pull of the blades when the airscrew is rotating.

In many designs this component is splined to the engine shaft and is also required to transmit the driving torque to the blades, but in others this torque is taken by an internal member, known as the spider, which is provided with arms on which the blades are free to turn.

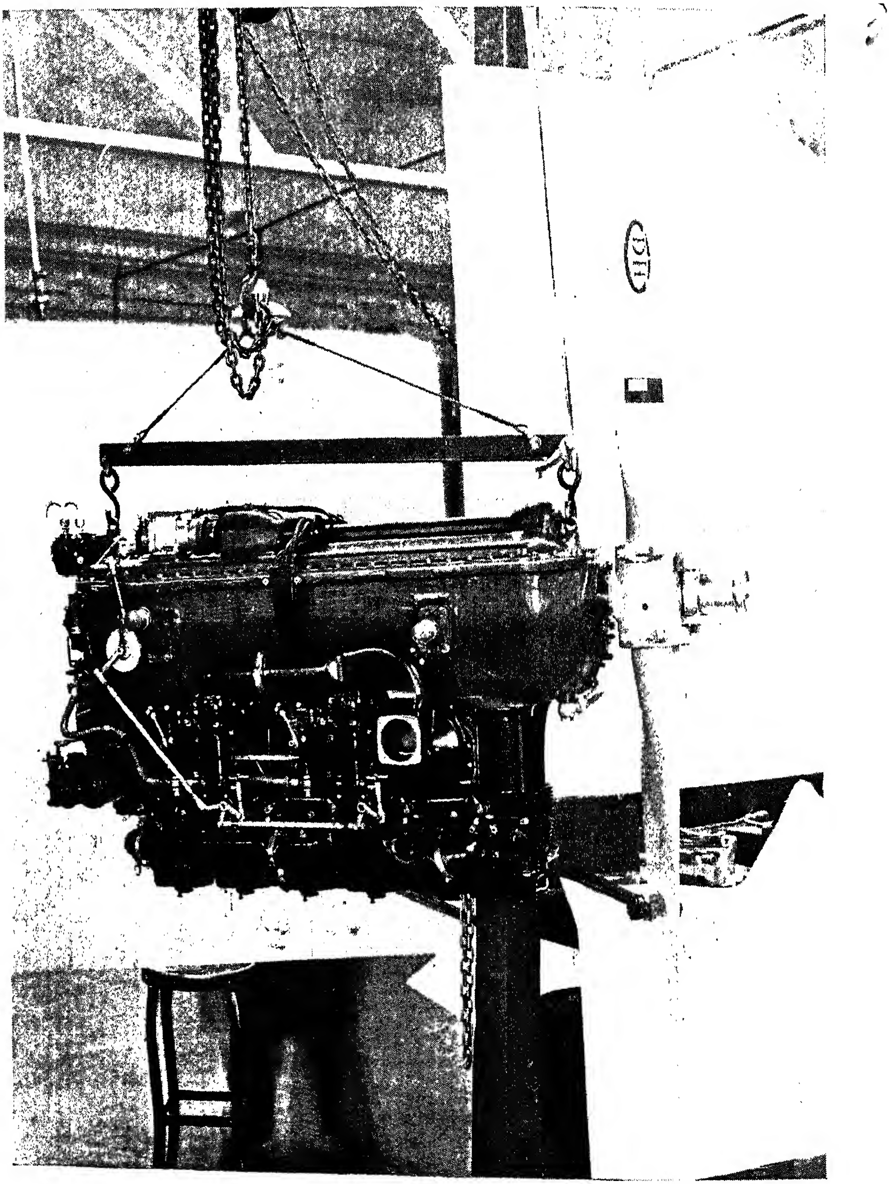


Fig. 3.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.

The 1,000 size controllable-pitch airscrew mounted on a Gipsy VI., Series II., engine.

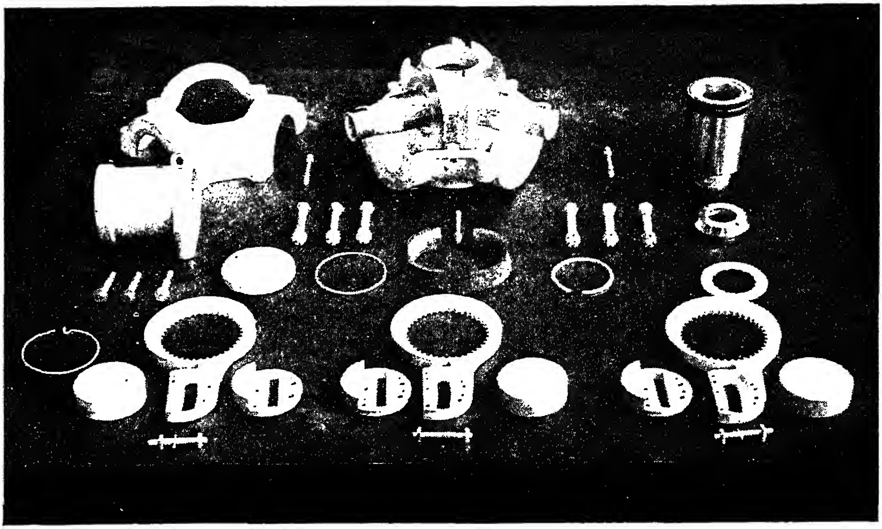


Fig. 4.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.
Component parts, less blades, of a 4,000 size three-blade airscrew.

Methods of Varying the Pitch

Various means of effecting the change of pitch angle are in use, amongst which may be mentioned : oil pressure from the engine lubrication system which operates in a cylinder built into the airscrew ; electric motors which are mounted on the airscrew hub and taking a current supply through slip rings move the blades through the medium of reduction gears ; air pressure and the centrifugal force of counterweights ; auxiliary windmills mounted co-axially with the airscrew and driving through clutches and gearing.

Materials of Construction

Whilst all heavily stressed parts, such as the barrel and spider, are made in high-tensile steel, a variety of materials is used for the blades, which, most often made in duralumin, are also manufactured in magnesium alloy, synthetic material, impregnated wood covered with celluloid, or sprayed metal, etc., all of which have some advantages peculiar to the particular material.

The de Havilland Controllable-pitch Airscrew

The British-built version of the Hamilton standard airscrew is the de Havilland controllable-pitch airscrew, which is now in production in large quantities, and accordingly this airscrew, which possesses most of

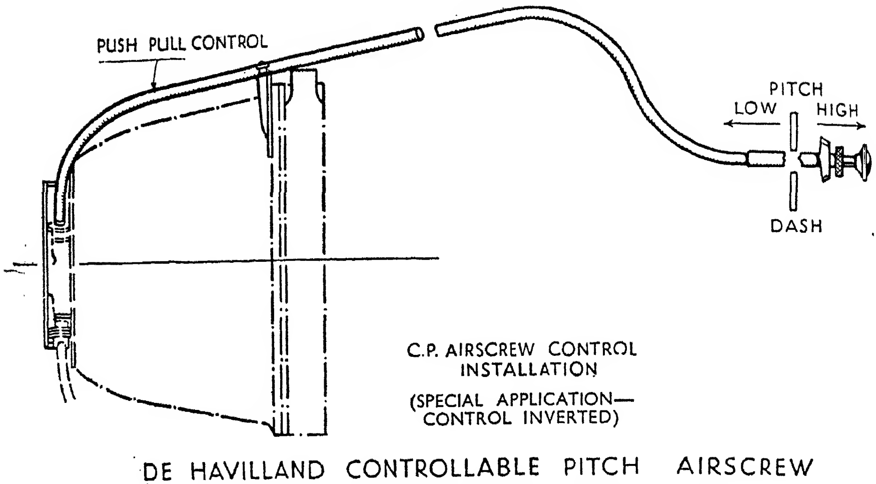


Fig. 5.—CONTROLLABLE-PITCH CONTROL INSTALLATION.

the features which controllable-pitch airscrews have in common, has been selected for illustration and description.

The designers have aimed at producing an efficient mechanism of simple and robust construction, with the minimum number of working parts.

Principles of Operation

This airscrew is not dependent upon extraneous or auxiliary sources of power which are often complicated and liable to derangement, but uses the engine lubricating-oil pressure to change into low pitch, and centrifugal force of counterweights to change into high pitch. These sources of energy, it will be noted, must always be available if the aeroplane is in flight, or is fit for flight.

Furthermore the stresses arising from centrifugal force and torque are catered for separately—the first being absorbed by the barrel, and the second by the spider.

In flight the natural tendency of the blades is to take up the high-pitch position under the centrifugal pull of the counterweights which is always in being when the airscrew is rotating ; and the low-pitch position is attained by admitting oil under pressure to a cylinder which then moves along a fixed piston, and through the agency of a cam motion forces the blades to take up the low-pitch position against the pull of the counterweights.

When the pressure is released, the blades are returned to high-pitch position and the oil in the cylinder is returned to the crankcase under the pull of the counterweights.

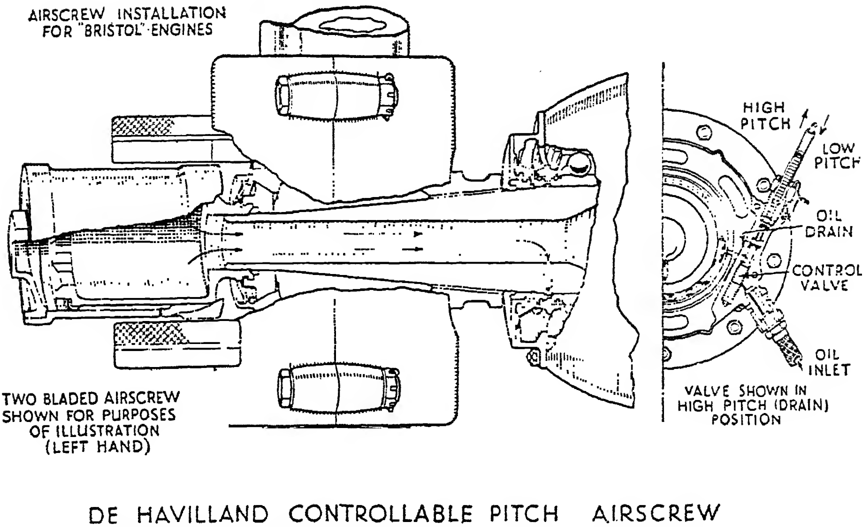


Fig. 6.—CONTROLLABLE-PITCH AIRSCREW INSTALLATION FOR "BRISTOL" ENGINES.

Provision for Mounting on Airscrew Shaft

Provision to mount and operate the controllable-pitch airscrew is now being made upon almost all types of aero-engines and usually takes the form of a channelled slip-ring or recess which surrounds the airscrew shaft and receives a supply of oil under pressure from the main gallery *viâ* a pipe in which is fitted a two-position cock or piston valve.

Coincident with the channel of the slip-ring a hole is drilled radially into the bore of the airscrew shaft, through which the oil passes to and from the operating cylinder.

Operation and Control

The two positions of the control cock or piston valve are "oil gallery to cylinder" and "cylinder to sump" and movement is effected from one position to the other from the pilot's cockpit by means of an approved type of control. The conventional method of installing these controls is to fit them so that they "follow the throttle," *i.e.*, they are pushed forward for high pitch and drawn back for low pitch.

The time required to change pitch varies with each installation, and also in accordance with a number of factors related to the conditions of flight obtaining, but in the most tardy cases it is never more than a few seconds.

It should be noted that whilst the foregoing brief description of the construction and principles of operation of the Hamilton Standard and de Havilland controllable-pitch airscrews refers only to two pitch positions,

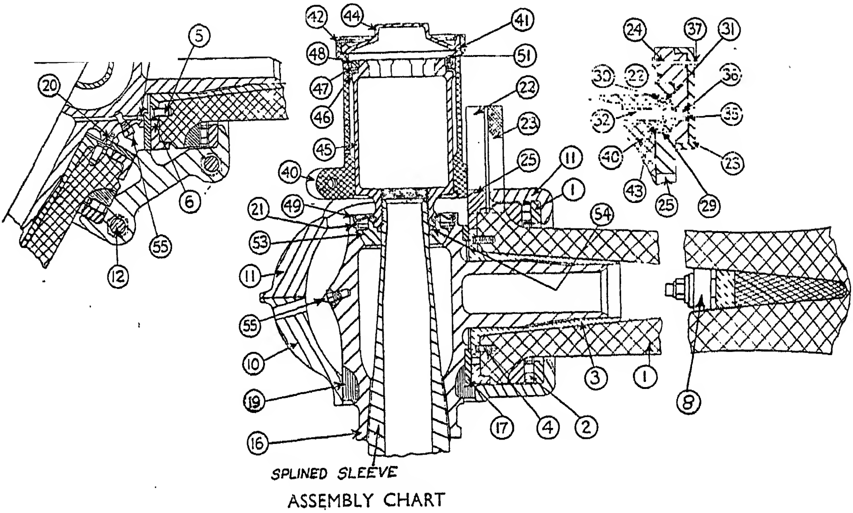


Fig. 7.—ASSEMBLY CHART.

all airscrews of this type are essentially constant speed airscrews, and only require the addition of a small pump and control unit which must be driven at a constant ratio to engine speed to give fully automatic control of engine speed and power.

Detailed Description of the de Havilland V.P. Airscrew

To continue with a more detailed examination of the airscrew—in this case the three-blade type—it will be observed that the whole assembly is carried on an internal member, which is called the spider (16).

How the Spider is Secured to Shaft

This component is bored and splined or tapered to fit the engine shaft on which it is secured and centralised at the front end by means of a cone (53) held up by the piston (45) which screws on to the end of the airscrew shaft in place of the airscrew nut.

Blades Attachment

It is provided with two or three arms on which the blades (1) pivot and which also transmit the drive torque to the blades. The spider, furthermore, is drilled and fitted with nipples (55) through which the internal bearing surfaces may be pressure-greased, the grease passing first into the bores of the spider arms, and thence through holes to the annular space between the large and small bushes and so on to the bearing surfaces.

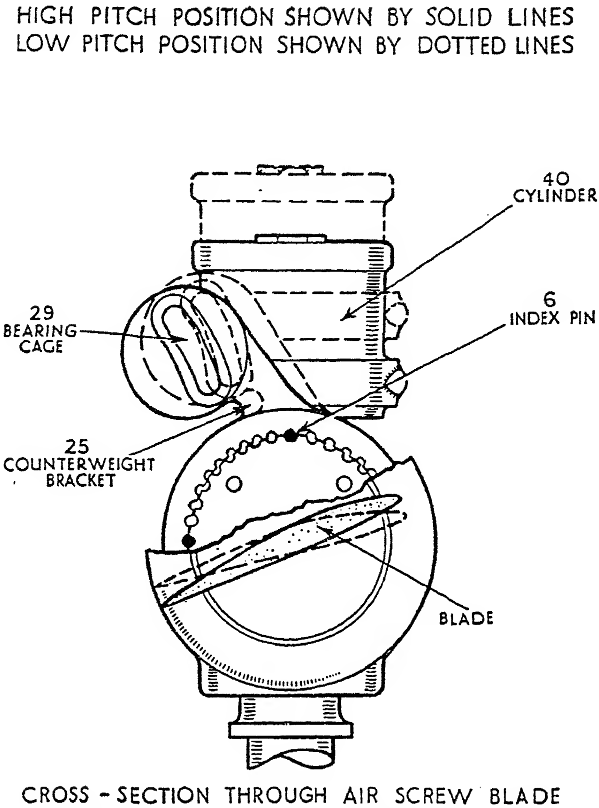


Fig. 8.—CROSS-SECTION THROUGH CONTROLLABLE-PITCH AIR-SCREW BLADE.

How the Barrel is Centred

At the rear the spider is formed with a circumferential groove into which is fitted a ring of synthetic resin and fibre (19) to act as a rubbing strake between the barrel (10) and (11) and spider and to keep the barrel, which otherwise is full-floating, centred around the axis of rotation.

Shim Plates and Greasing Nipples

Concentric with each spider arm at the root a spigot is provided to position the shim plate (17), whilst mid-way between each pair of arms the greasing nipples are screwed into the spider hub, where they are accessible to the grease gun through apertures in the barrel.

The Snap Ring

At the front end the spider is provided with a snap-ring (21) let into a recess immediately in front of the cone seating to provide a purchase against which the cone can bear, and so withdraw the hub from the engine shaft when the piston is unscrewed.

The Locking Ring

It has also a recess to accommodate a locking-ring (49) which employs male and female octagonal location on the neck of the piston, and is secured to the hub at its periphery through close adjacent flanges by split pins.

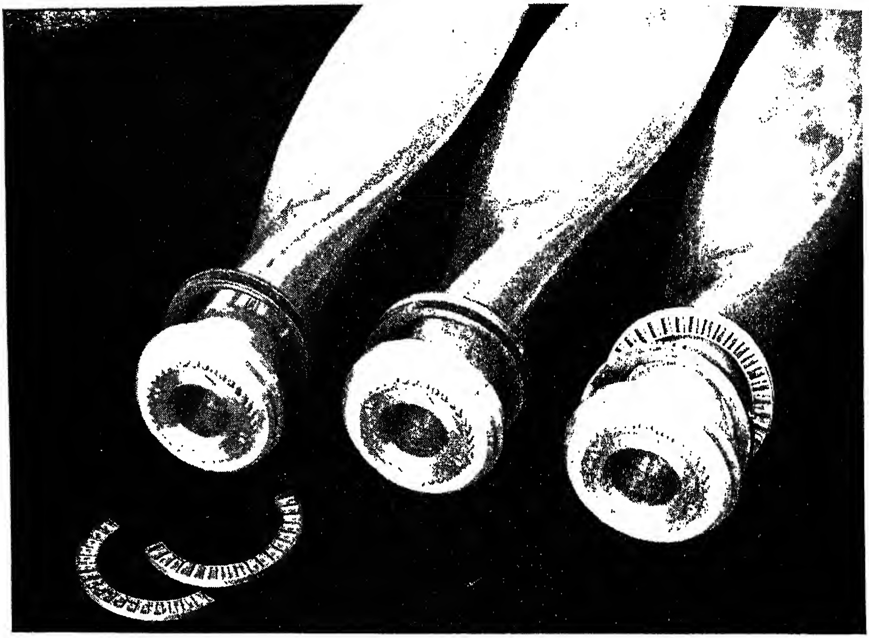


Fig. 9.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.

Blades for a 4,000 size airscrew, showing arrangement of roller races, and locating and fixing arrangements for securing the blade bushing.

The Front Cone

The front cone (53) is a close fit on the airscrew shaft and is ground to fit accurately the seating in the front end of the spider. It is provided with a recess on its outer face and is split across a diameter to permit of its being assembled round a flange on the neck of the piston by which it is withdrawn.

Between the flange of the piston and the front cone provision is made for a leather packing-washer (54) which prevents leakage of oil along the piston threads.

The Actuating Piston

The piston (45) is a hollow cylinder of steel provided with a thread and locking arrangements at one end by which the whole airscrew and the piston itself are secured to the engine shaft as already described.

It is also open at the large or outer end where the aperture is shaped to take the box spanner by which the piston is turned.

Around the piston at the outer end are fitted two "L" sectioned leathers (46) and (47), back to back, which are held in position by a ring-nut (48) and effect the oil sealing of the piston in the bore of the cylinder.

The Cylinder

The cylinder (40) is a duralumin forging which is closed at its front end by a cylinder cover of steel (44) screwed down upon a copper-asbestos joint-ring (41)—the cylinder and cover being locked together through their flanges by the tang of a spring locking-wire (42) which is sprung into a groove round the inside of the cover flange.

The Counterweight Bearing-Shafts

At the rear or open end the cylinder is a close fit round the piston and is formed externally with a wide thick flange, which is milled away to leave two or three bosses (for either two or three blades) into which are screwed the counterweight bearing-shafts (32) which are the connecting links between the operating cylinder and the blades.

As these bearing shafts are subject to various and considerable stresses in use and at the same time are constrained to small limits of fit and wear by the design, special arrangements have been made to secure them in the cylinder flange.

The bearing shafts are produced to fine limits on the overall length and in order to secure interchangeability a small steel plug is pressed into the tapped hole in the cylinder flange, cuttered to gauge in position and the bearing shaft is then screwed hard down upon it.

To support the shaft at the outer end a bronze bush (43) is pressed into the cylinder flange and reamed in position to a push-fit on the shaft, when it is faced on its flange to provide a specified clearance at the back of the counterweight bracket (25). The bush is, in effect, merely a replaceable stiffening to the bearing-shaft bore—there is no relative movement—and the whole assembly is locked by a split pin which passes through the cylinder flange, bush and bearing shaft.

The bearing shaft at the outer end is formed with a head which is mitred on the underside and is continued on the upper side of the head where it forms a boss about $\frac{3}{16}$ in. high.

This shaft is screwed into the cylinder flange through a ball race (29), (30) and (31) of special design which is accommodated in a curved recess milled in the counterweight bracket—the bevel under the head locating in a seating in the small race and the extension to the head projecting into the slot in the counterweight where the travel of the shaft is determined by the stop nuts (35) on the adjusting screw (36).

Thus assembled, the bearing shaft takes through the ball race the whole of the centrifugal load and turning moment of the counterweight (22). By reason that the locus of the shaft is inclined to the slot in the counterweight, it operates—and in turn is operated by—the latter in the process of changing pitch.

The Counterweight

The counterweight is dowelled to the counterweight bracket and

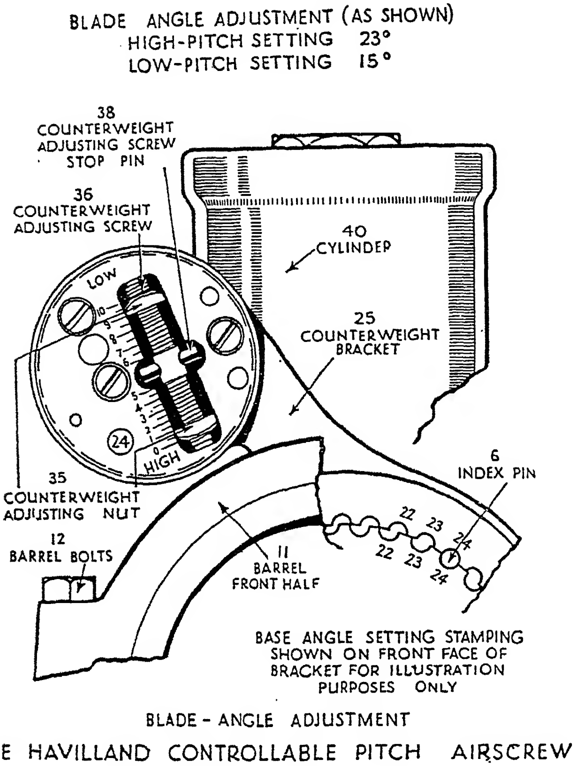


Fig. 10.—BLADE ANGLE ADJUSTMENT.

secured thereto by cheese-headed screws locked by spring washers. The weight of the counterweight assembly requires to be determined closely and is adjusted by means of a type-metal filling in the cap (23) which screws on to the counterweight on which it is secured by a locking pin (24) in shear and a split pin (37).

The Blades

The various materials referred to in a previous paragraph are resolved into blade forms by processes most of which are highly specialised. All are designed to utilise the peculiar properties of the material to best advantage in a component which is subjected to very severe and constantly varying stresses in flight.

Metal Blades

Metal blades are produced by forging, and in some cases they are also rolled or extruded in order to improve the grain-flow and enhance the strength of the material.

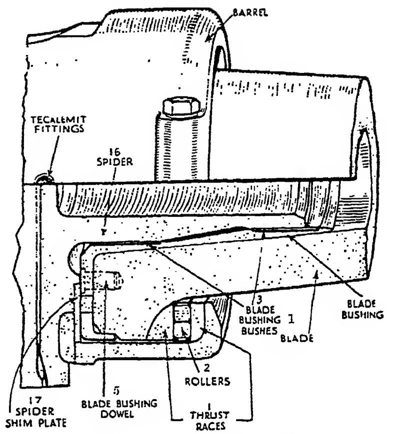
Synthetic Material Blades

Synthetic material blades are both moulded under pressure in heated dies and carved from blocks of material specially prepared.

Wood Blades

Wooden blades are often compressed at the root to receive a steel sleeve by which they are attached to the hub and are impregnated under pressure with synthetic resin, finally to be finished with an outer coating of sprayed-on cellulose preparation, synthetic resin or metal which keys on to a prepared foundation.

Manufacture of Duralumin Blades



CROSS-SECTION BLADE & SPIDER

DE HAVILLAND CONTROLLABLE PITCH AIRSCREW

Fig. 11.—PART-SECTION OF BLADE AND

Only duralumin blades are at present being produced in quantity. The description hereafter refers only to that type.

The blade is prepared in the form of a billet, which is then rolled, drop forged and up-ended into a form closely resembling the finished blade. The whole of these operations are planned to produce an undistorted grain-flow within the material; and it is noteworthy that the roller races, which in service take the centrifugal pull of the blades, are put in position over the end of the shank before it is up-ended.

The forging is supplied in the finally heat-treated and age-hardened condition to the blade-shaping shops, where it is shaped to a master on semi-automatic machines. Owing to the variations of width and thickness of the blade section, and to the release of surface stresses as the outer skin is removed, some distortion of the blade shape invariably occurs, and to remove these errors it is necessary to finish-grind the blades by hand.

This last operation, which is extremely critical and calls for a high degree of skill, is carried out with frequent checks of edge and face alignment, section and helix angle by means of templates.

A hollow shank, weight for weight, being stronger than a solid shank, advantage is taken to provide a tapered bore which is used to effect the balance of the airscrew and to accommodate in suitable bearings the arm of the spider through which the driving torque is transmitted to the blade.

To provide replaceable and adjustable bearings for the spider arm, the blade end is fitted with a steel or alloy bushing (3) which is pressed and shrunk into position and secured by screws (4) and dowels (5).

The flange of the bushing, which is provided with thirty-six half holes equally spaced, is surrounded by a flange formed in the counterweight bracket which has forty half-holes equally spaced, and four small pins or plugs (6) are inserted, a light tap-fit into the complete holes thus formed, 90 degrees apart, between bushing and bracket flanges to lock them together.

Provision for Weight and Balance Adjustments

The blind end of the blade bore provides accommodation for lead

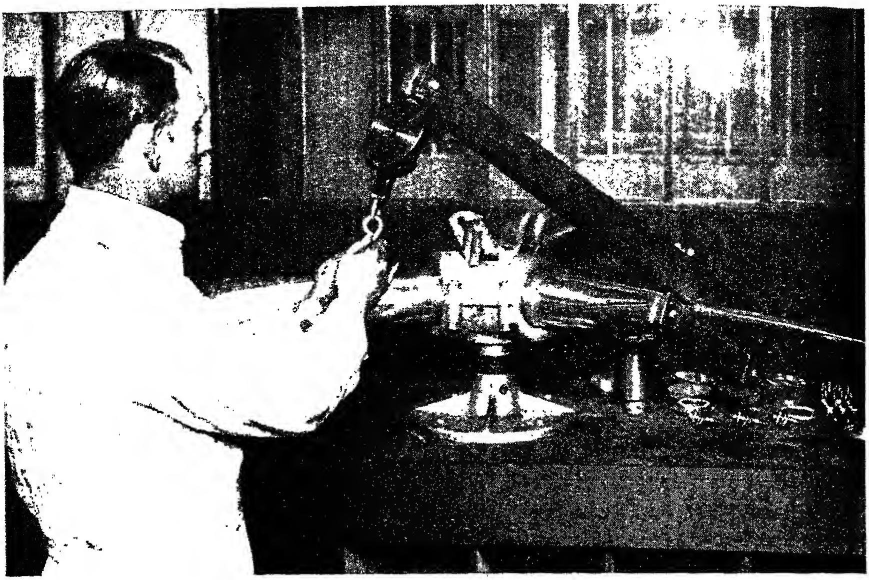


Fig. 12.—CHECKING TORQUE LOADING.

wool required to adjust major differences in weight and balance. Lower down, the adjustable blade plug (8) is fitted which carries a number of washers on a central stud and is designed as a means to effect minor adjustments to balance.

The Roller Race

Externally at the root a radius is formed against which the inner member of the roller race abuts. Great importance is attached to the fit of this component since, in flight, it is called upon to carry a very considerable live load—the centrifugal pull of the blade in an average-sized airscrew often exceeding 30 tons.

The roller race which carries this load comprises an inner and outer race with a phosphor bronze cage (2) containing a double row of rollers sandwiched between them. The cage requires to be split across a diameter to permit assembly and the arrangement of rollers adopted is designed to secure a uniform distribution of load and to reduce skidding of the rollers as much as possible.

The Barrel and its Function

The barrel is a two- or three-way forging—depending upon the number of blades in the airscrew—which is made in front and rear halves and bolted together, the joint being in the plane of rotation.

The principal function of the barrel is to absorb the centrifugal pull

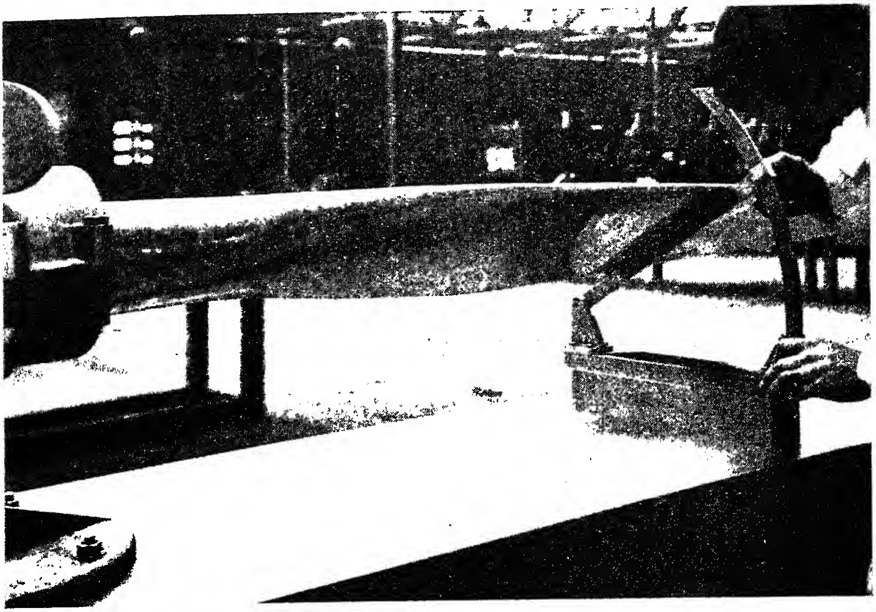


Fig. 13.—CHECKING BLADE ANGLES ON SURFACE TABLE.

of the blades when rotating and, being fully floating, it is free to adapt itself to any small inequalities of adjustment. The front half is cut away to clear the cylinder and the counterweights ; whilst the rear half is bored a fit to the barrel chafing-ring surrounding the spider.

Internally a good deal of machining is done in order to lighten the assembly and to give a better stress distribution in the material ; whilst the bolts (12) which secure the two halves are made hollow up to a point just below the commencement of the thread. This bore is used for small adjustments to balance, which are effected by tapping lead-wool into the bolt, and at the same time it reduces the cross-section to that through the threaded portion, thereby avoiding concentration of stress and removing any possibility of failure from this cause.

The Shimplate and Why it is Necessary

The shimplate is inserted between the end of the blade and the spider on which it is located by the spigot, referred to in a previous paragraph. It is of hardened and tempered steel, carefully ground to a flat surface on both sides. It is dowelled to the spider to prevent rotation, but since it fits the barrel tightly at its periphery it is provided with clearance at the dowel (20) and spigot in order not to bind the assembly. Later types are fitted with a rubbing strip secured to the edge of the shimplate with Formica cement.

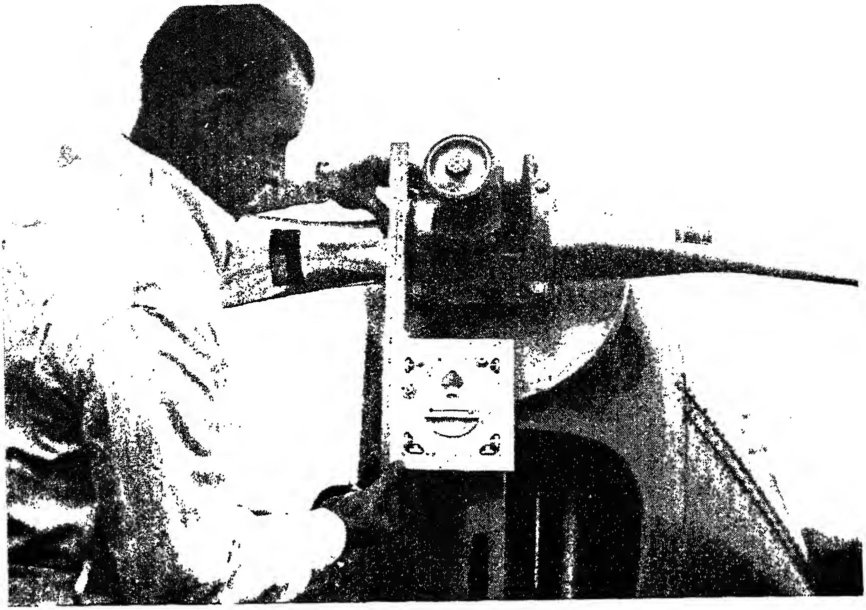


Fig. 14.—Checking blade angle.
Setting blade truly horizontal.

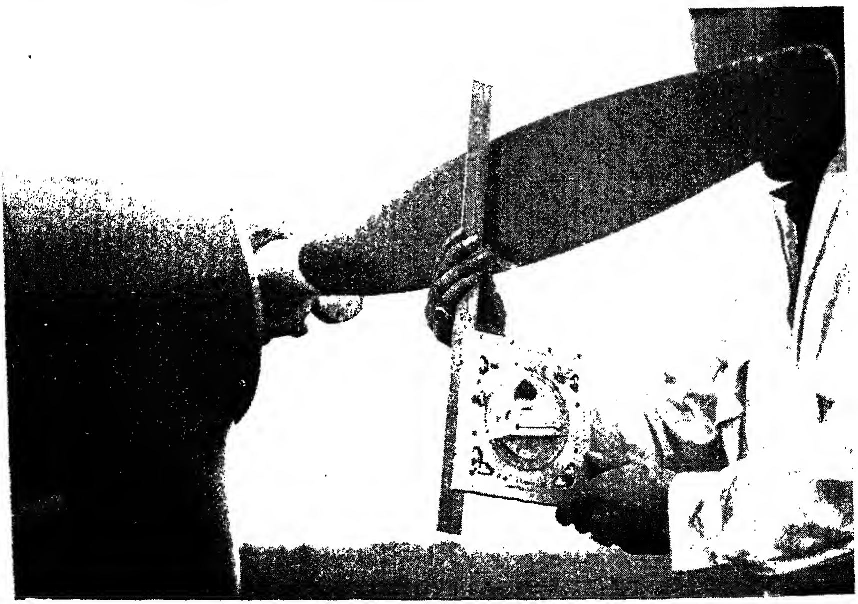


Fig. 15.—Checking blade angle.

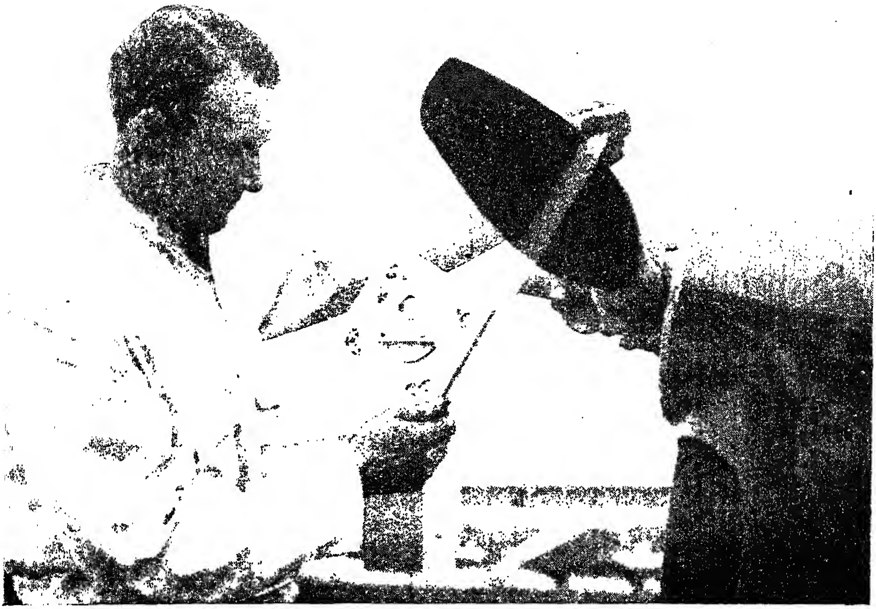


Fig. 16.—CHECKING BLADE ANGLE.

Although simple in shape and design, the shimplate is an important item in the assembly, since it provides a means of adjusting the torque loading of the blades, acts as buffer between the blade bushing and the spider and absorbs much of the wear which otherwise would occur on these expensive components.

Spigoted to the spider and a tight fit on the outer diameter in the bore of the barrel, it keeps the spider arm permanently centred in the barrel aperture and so prevents damage to the blade shank from contact with the lip of the barrel.

Finally, it serves to retain the index pins which key the blade to the counterweight bracket and prevents the displacement of this last component at the root of the blade.

The most important of these functions is to adjust the blades within the barrel to give a torque loading in the static condition which will be indicative of freedom to move and change pitch when the airscrew is rotating.

This torque loading is necessary since the very considerable centrifugal pull of the blades, previously referred to, is taken by the barrel through the roller races at the roots of the blades and its effect is so to stretch this component as to give rise to undesirable slackness of the blades when the airscrew is rotating unless they are pre-loaded in course of assembly.

The manufacturing tolerances on spider, barrel and blade roots may cumulate to relatively large amounts, and it is required, therefore, to assemble each airscrew with shimplates of varying thicknesses in order to obtain this pre-loading which is measured in lbs.-ft. by means of a dead weight or spring balance attached to a lever which is clamped to the blade near the root.

Shimplate Ranges

The initial torque loadings for new airscrews vary up to 50–90 lb.-ft. for the larger sizes and to obtain these values a range of shimplates varying in thickness by 0·0005 in. is required.

To facilitate this adjustment a new arrangement of shimplate is now in production, which consists of a much thinner plate built up to the requisite thickness by means of a pack of shims behind it, which being built up of laminæ on the one side 0·001 in. (one thousandth) thick and 0·0015 in. (one and a half thousandths) on the reverse can, by careful peeling, be adjusted by the half-thousandth's stages required.

After considerable running time it is usual to find that the torque loading has increased in value due to the blade bushings working back slightly in the bores of the blades.

This process, however, is self-regulating, and it is not necessary to re-adjust the torque loading to its new value providing the blades are moveable in the hub and turn smoothly.

The Counterweight Bracket

The counterweight bracket is a lever through which the blades are turned from one position to the other, either by the counterweight bearing-shaft operating in the curved slot at its extremity, or by the centrifugal force of the counterweight which is attached thereto.

The Vernier Adjustment

At its inner end it is recessed to fit snugly round the root of the blade, and is provided with forty half-holes which match up with the thirty-six half-holes provided on the periphery of the blade bushing for the purpose of providing a variable basic angle setting for the blade.

This arrangement permits a vernier adjustment of 1 degree being made to the initial setting of the blade. At the other end a screw with adjustable stop nuts is positioned in the slot of the counterweight to limit the travel of the counterweight bearing-shaft in the slot.

The first of these adjustments is known as the basic setting and its value in degrees will be found stamped on a lead plug provided in the counterweight for the purpose.

The second is, in effect, the range through which the airscrew can be changed from high to low pitch and the values of this last adjustment must always be subtracted from the basic adjustment figure in order to

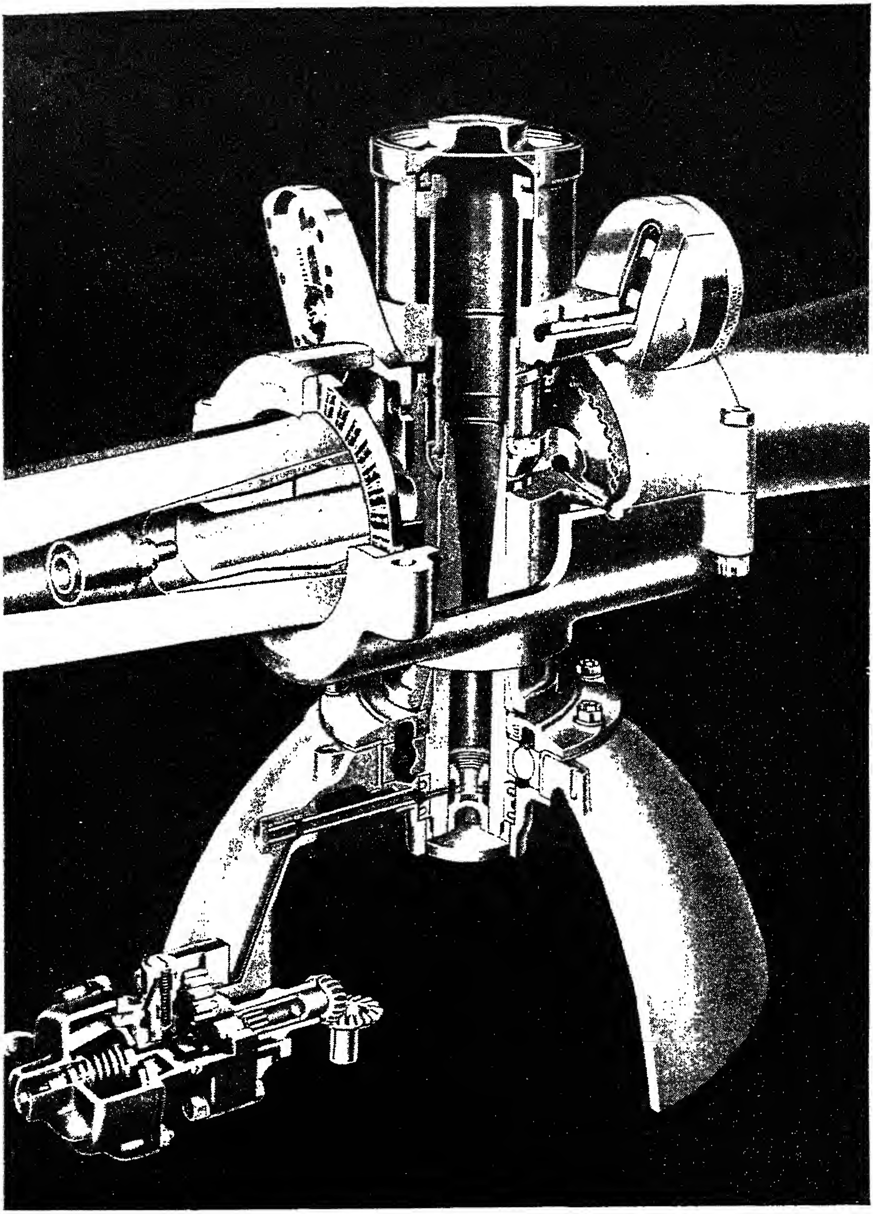


Fig. 17.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.

Part section of 4,000 size controllable-pitch airscrew with constant speed control unit incorporated. Airscrew in high pitch position.

determine the actual angle of attack of the blade. On the largest types it is measured at a radius of 42 in. from the centre line of the airscrew and on the smaller types at a distance of 30 in. from the centre line.

Using the Vernier Adjustment

The basic setting will also be found stamped in degrees on the blade bushing and on the counterweight bracket-flange opposite the half-holes which, when brought to coincide and secured by the insertion of an index pin, will give the basic setting indicated at the appropriate station with the high pitch stop in the counterweight at zero.

To procure uniformity of position for these markings, that half-hole on the bracket, which is cut by a line prolonging the straight edge against which the counterweight locates on the bracket, is used as a point of origin from which to locate the half-hole, which is stamped with the basic setting number.

The scale of degrees marked on the counterweight will be seen to stretch out somewhat on the low-pitch side, but for the purposes of adjustment it can be assumed that a quarter turn of the adjusting nut corresponds to three minutes of pitch angle on the blade—or five complete turns to 1 degree.

Similarly, 1 degree change of pitch will usually effect a change in airscrew r.p.m. on the ground of from 2½ per cent. in the case of supercharged engines, to about 3½ per cent. for engines with normal aspiration. In the air, both types will vary their r.p.m. by about 4 per cent. for 1 degree change of pitch.

These figures are merely a basis for trial and error adjustments. When used with engines employing a reduction gear, they should be multiplied by the reciprocal of the gear ratio in order to arrive at the corresponding crankshaft or revolution indicator r.p.m.

The care and maintenance of the variable-pitch airscrew is dealt with in Volume III.

CONSTANT-SPEED AIRSCREW

Whilst the variable-pitch airscrew is a great advance on the fixed-pitch type, it is yet in a position analogous to that of a car having only one alternative gear, which, therefore, would have to be of a ratio to enable the car to climb a maximum specified gradient. Such a car would climb all lesser gradients, but would be extremely wasteful of both time and engine power and the engine would require to be throttled to avoid excessive r.p.m.

The Perfect Solution

The perfect solution of this problem is, of course, the infinitely variable gearbox, which adjusts the load as required to maintain a constant speed

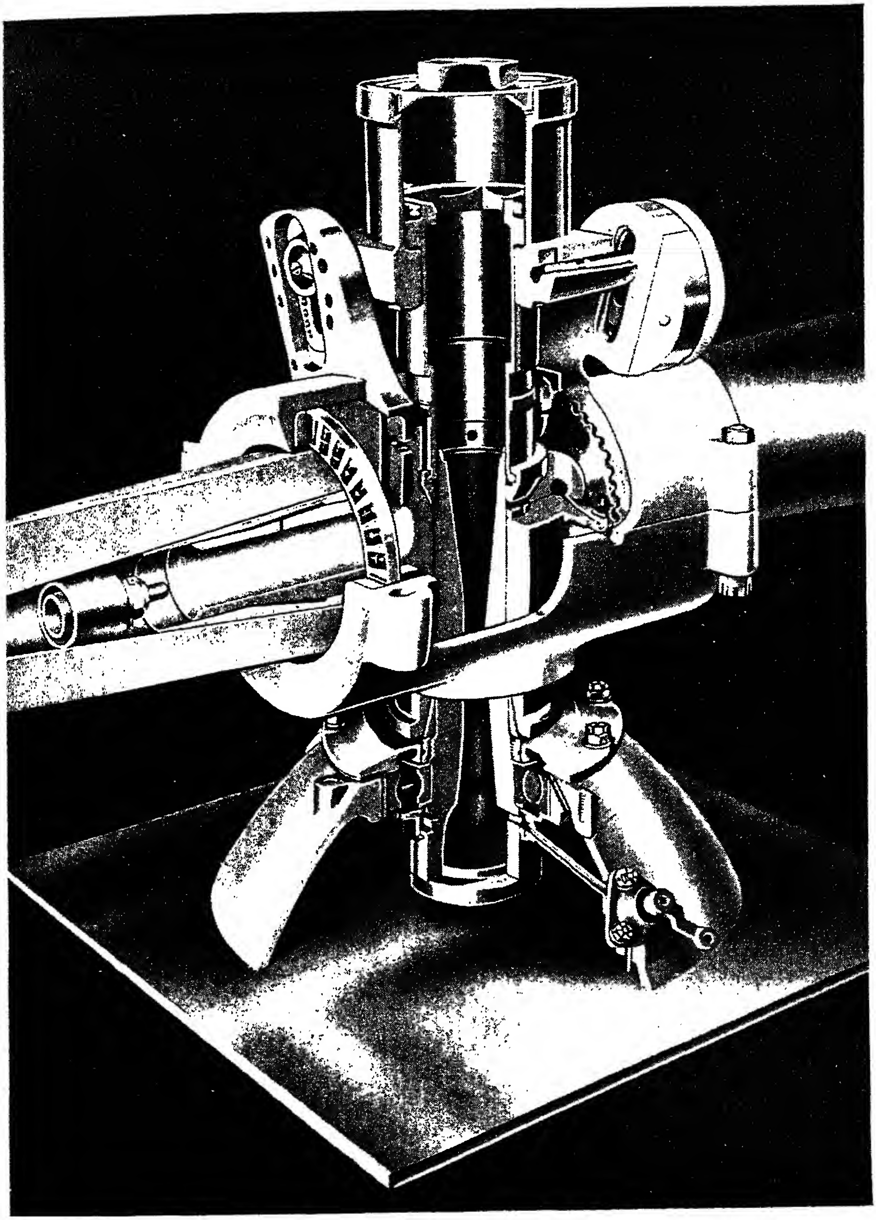


Fig. 18.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.

Part sectional controllable-pitch airscrew in low pitch. See also Fig. 17.

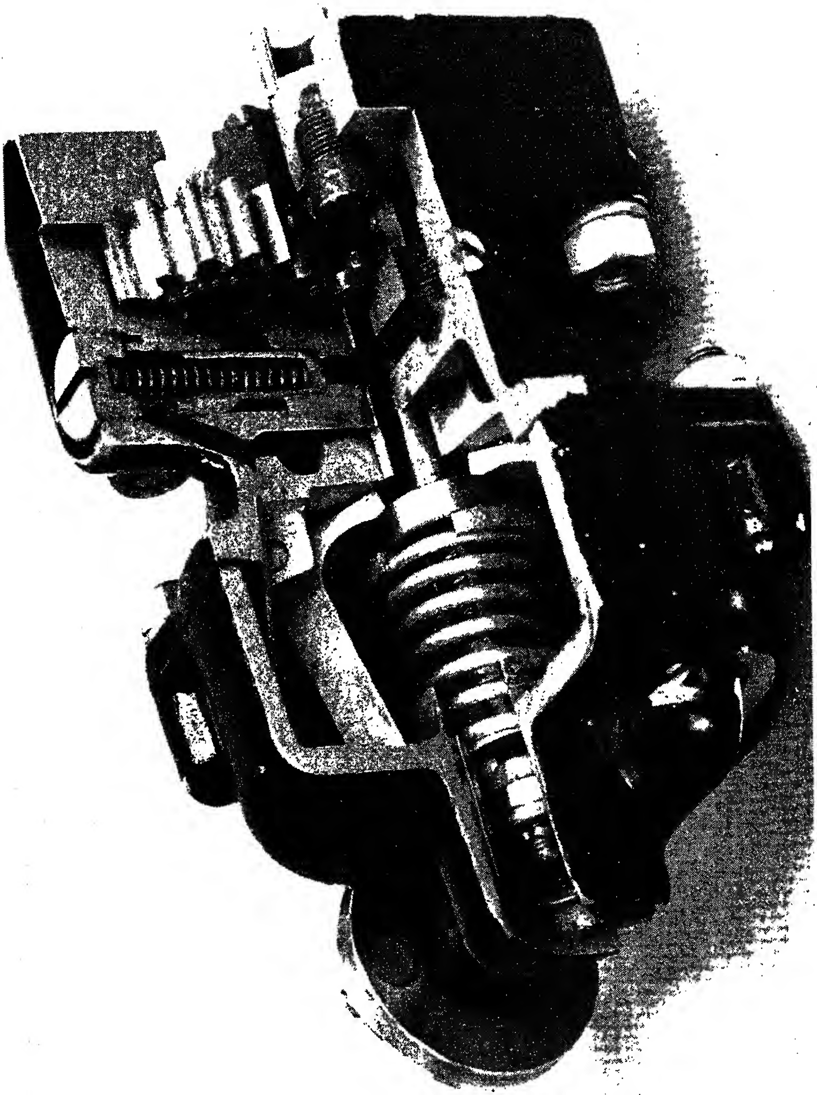


Fig. 19.—DE HAVILLAND CONTROLLABLE-PITCH AIRSCREW.

Sectional constant speed unit. The screwed plug in the base plate can be placed in alternative positions for either direction drive.

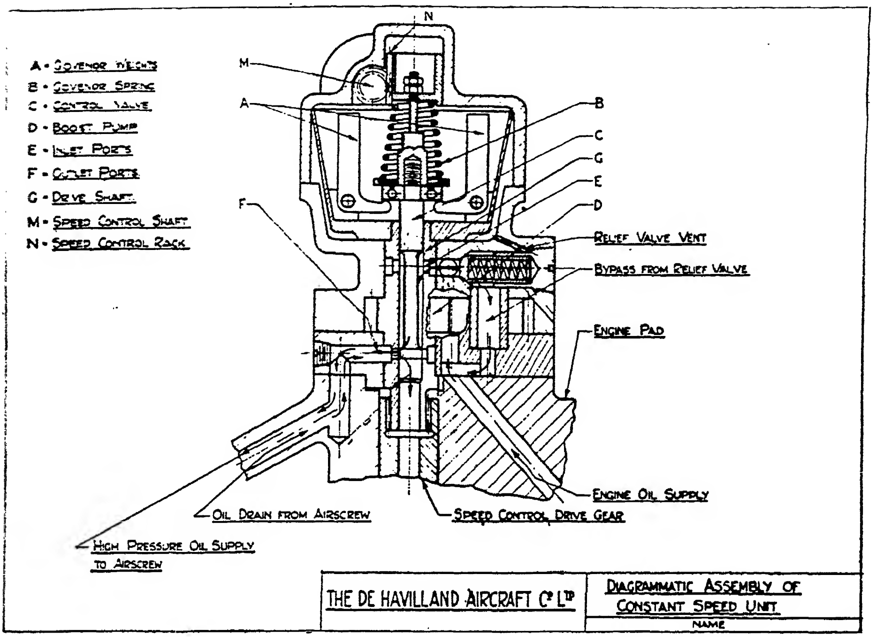


Fig. 20.—DIAGRAMMATIC ASSEMBLY OF CONSTANT SPEED UNIT.

at the engine crankshaft with a fixed throttle opening, but in standard car practice it is only possible to approximate these conditions, and it is usual to fit a gearbox giving a choice of three or four ratios.

A Close Approximation

The constant speed device, however, used in conjunction with the variable-pitch airscrew approaches very close to this ideal, and, in effect, it governs the speed and power of the engine within very narrow limits over a very wide variation of load—in other terms, in all reasonable positions of the aeroplane in flight—without assistance from the pilot.

Over-riding controls are provided to enable the pilot to obtain maximum permissible revolutions for take-off if required or they can be set or altered as readily as the throttle to give a predetermined engine r.p.m. which speed will then be maintained automatically by the governor in all but the most exceptional angles of take-off, climb, level flight and landing approach, with considerable economy of fuel and engine wear and relief to the pilot.

The Automatic Control Unit

The control unit is simple and robust in design and consists of a small gear-type pump which is fed from the engine main oil-supply, and which

delivers to the airscrew at a constant pressure—maintained by the conventional type of relief valve—of about 200 lb. to the square inch.

A pair of flyweights, driven by gearing from the engine, actuate a small piston valve which admits and releases this oil to or from the cylinder, admitting it when the speed falls, and so reducing the pitch of the blades, and *vice versâ*.

The Pilot's Control

The pilot's control is effected through a spring by means of which he can pre-load the piston valve to any value he chooses against a scale of engine revolutions.

The governing action is initiated by the speed variation, but such is the sensitiveness of control that no variation can be detected in normal flight and "hunting" is almost completely damped out.

The design and serviceability of the constant speed unit have been thoroughly tested, and such is its reliability that it is guaranteed to run without attention for five years, when it can be replaced equally conveniently as a magneto.

Provision has not, therefore, been made for the supply of spare parts, and all time-expired or defective units should be returned for overhaul to the manufacturers' works, where the necessary equipment for overhaul, adjustment and test is available.

Detailed Description

The unit comprises a gear-type oil pump and a governor which controls the flow of oil to and from the airscrew by means of a piston valve, all of which are contained in one casing.

As normally fitted, the unit is bolted and jointed to a prepared face on the engine crankcase, in which are provided oil supply and drain passages, and is driven from any convenient member or assembly which is rotating in fixed ratio to the crankshaft.

The drive is transmitted to the constant speed unit through a splined connection, and requires to turn in certain ratio to engine speed in order that the full governing characteristics of the unit may be obtained over the more important section of the speed range.

Oil is fed to the unit under pressure from the engine oil system and passes into the geared pump, where the pressure is boosted up to about 200 lbs. per square inch, at which point the relief valve lifts and permits the surplus oil to regain the inlet side of the pump.

The governor is mounted upon an extension of the spindle which drives the pump, and comprises two "L"-shaped flyweights which are pivoted at the angle, a metal cup containing the flyweights and rotating with the spindle, a piston valve which slides in the bore of the hollow

spindle, and a spring by means of which the loading on the governor can be varied.

These parts in their correct relation can be seen in the photograph of a sectioned unit on page 178.

The shaft, pump-driver gear, cup and flyweights revolve as one unit, whilst the piston valve, its loading spring and the plunger operating the loading spring are anchored to the cover and have only a reciprocating motion.

On the upper end of the piston valve is mounted a small radial ball race, whose centre remains stationary and takes the thrust of the loading spring whilst its outer race rotates with the flyweights and takes the lift or thrust which results from the tendency of the flyweights to move outwards under centrifugal force.

It will be noted that centrifugal force is always acting against the spring, and will, for any variation of speed, achieve a balance either by compressing or permitting the elongation of the spring whilst concurrently moving the piston valve in one direction or the other.

The waisted section of the piston valve is surrounded by oil at a pressure of about 200 lbs. per square inch, and immediately any downward displacement occurs—corresponding to a reduction of r.p.m. and centrifugal force and an ascendency of the r.p.m. spring—a port in the spindle bore is uncovered and oil is passed *viâ* an annular collecting chamber into the airscrew-operating cylinder, so forcing the blades into low pitch as far as may be required to restore the speed to the controlled level.

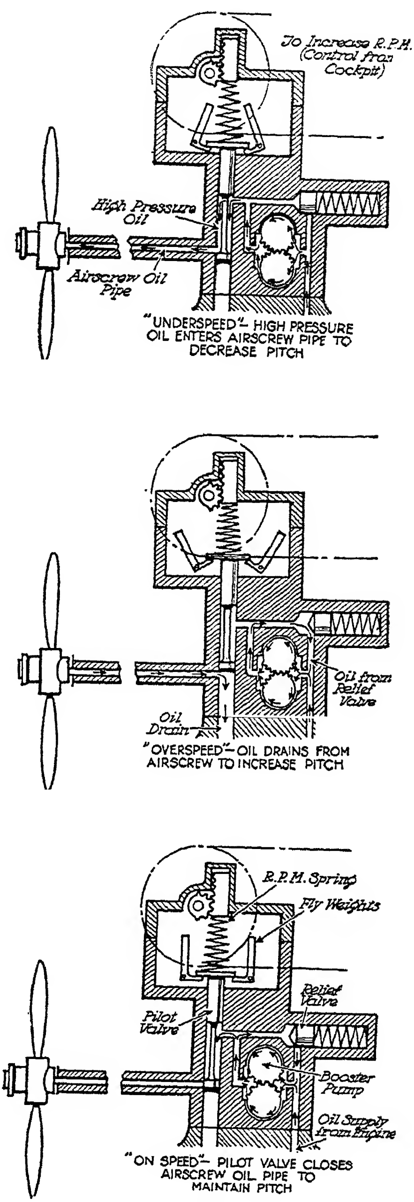


Fig. 21.—DIAGRAMMATIC REPRESENTATION OF AIRSCREW, CONSTANT SPEED CONTROL AND BOOSTER PUMP FOR THREE DIFFERENT OPERATING CONDITIONS.

Conversely, if the speed rises, the piston valve is lifted and the oil drain opened, when the balance weights of the airscrew can return the blades towards high pitch until decreasing revolutions return the piston valve to the neutral position and prevent further escape of oil from the cylinder.

To alter the speed, therefore, it is only necessary to adjust the load on the r.p.m. spring, so displacing the piston valve, which will then admit a flow of oil to or from the airscrew-operating cylinder and permit the blades to move until the change in r.p.m. at the governor is sufficient to restore the piston valve to the neutral position.

In flight there is continual movement of the governor and piston valve, since many factors affect the speed of the airscrew and tend to vary it, whilst only the momentum of the airscrew itself is opposing these influences ; hence it is of paramount importance that the control unit should be susceptible to very small changes of r.p.m. in order to prevent surging or " hunting " in the installation.

In the more orthodox piston valve and servo motor design a good deal of hesitation occurs where it is desired to make the movement proportional to the actuating load and initially the load is small, because the valve working with a small clearance tends to stick, and requires additional pressure to shear the oil film before it can move.

Immediately the resistance of the oil film has broken down, however, the accumulated force produces a relatively large movement of the valve which over-corrects the error and induces a similar phase in the opposite direction, resulting in a surging in the controlled motions which will be proportionate to the inertia or " stickiness " of the valve.

This " hunting " is quite inadmissible in a constant speed control, and is avoided by restraining the piston valve from rotation in the bore of the driving shaft, which turns at high speed.

The oil film between the piston valve and its cylinder is thus always in shear, and the slightest alteration to the axial loading of the valve produces an instant and proportional movement of the valve itself, so effecting a control of great sensitivity which is, for all practical purposes, dead-beat.

The cup surrounding the flyweights, which is cut away in the part-sectioned illustration to disclose the interior arrangements, is added to prevent contact between the flyweights and the casing, should the engine for any reason greatly exceed its maximum permissible r.p.m.

In effect, the cup by arresting the outward swing of the flyweights determines the upper limit of the r.p.m. range through which the unit controls the engine speed.

In addition, it acts as an oil centrifuge, and any oil gaining access to the cup rotates with it and is quickly discharged at the edge by centrifugal force.

By this means oil is prevented from interfering with the action of

the governor, even should it appear in quantity in the casing, and it enables the constant speed unit to be fitted in any position which may be convenient from the installation or the engine manufacturers' point of view.

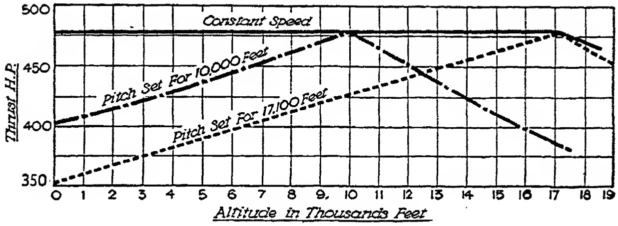


Fig. 22.—COMPARISON OF POWER AVAILABLE IN LEVEL FLIGHT WITH FIXED-PITCH, TWO-PITCH AND CONSTANT SPEED AIRSCREWS AT CRUISING PRESSURES.

The curves relate to an engine of 750 b.h.p. at 10,000 and 1,667 r.p.m. airscrew speed; and aeroplane with a speed of 250 m.p.h. at 10,000 ft.; and three-bladed airscrews of 10 ft. diameter. The cruising limits of engine operation are 563 b.h.p. and 1,513 r.p.m.

The operation of the unit will be clear from the diagrams showing the conditions of "under-speed," "over-speed" and "on-speed," in which respectively oil is being forced into the airscrew to reduce the pitch and increase the revolutions; in the second case it is being released from the cylinder to drain, enabling the airscrew counterweights to increase the pitch of the blades so decreasing the revolutions, whilst in the third case the airscrew is on-speed and the port is closed.

In this last condition the counterweights are holding the blades hard up to the oil imprisoned in the cylinder, and no further movement can occur, meanwhile the whole volume of oil delivered by the pump is circulating through the relief valve.

It will be apparent that little oil is required by the unit in normal operation, as the movements of the cylinder, though continuous, are small in amplitude.

In order to secure a quick response to the governor control, however, the geared pump has been given a capacity of $2\frac{1}{2}$ gallons per minute at a speed of 1,750 r.p.m., which is ample to operate airscrews much larger than any in production at the present time.

The ratio of the drive between crankshaft and constant speed unit is determined by the rated speeds of the engine in relation to the characteristics of the unit, and exercises control over a range of 2,800–1,200 r.p.m. of the governor spindle.

For most installations it is recommended that at the maximum rated speed of the engine in level flight the constant speed unit should be geared up to a speed of 2,520 r.p.m., which is 10 per cent. less than the upper effective limit of 2,800, but this rule is varied for special military applications, such as dive bombers, etc., where the operational requirements are abnormal.

Whilst the constant speed unit is proportioned to operate the largest size airscrew, it only weighs about 4 lbs., and the saving of weight which

might be effected by introducing alternative sizes with reduced outputs for smaller airscrews is completely outweighed by the advantages of maintaining 100 per cent. interchangeability ; and only one size therefore is manufactured.

Operation

The effect of the governor in maintaining a constant r.p.m. completely destroys the value of the r.p.m. indicator as an index of the mixture strength or the power being taken from the engine, since any such alterations are accompanied by a change of pitch, but no change in r.p.m. occurs.

It is desirable, therefore, to provide for automatic mixture control in the carburetter, and a " boost gauge " to measure the pressure in the induction chamber which is a reliable indication of the power the engine is developing.

With such a system the pilot only requires to adjust his throttle occasionally whilst gaining or losing height to maintain a constant manifold pressure in order to keep engine and airscrew working at maximum efficiency.

Advantages of Constant Speed Operation

The advantages conferred by the constant speed device are most apparent in the case of high performance aircraft fitted with supercharged engines, as almost invariably reduction gears are employed, and a very considerable change of blade angle is necessary to meet the requirements of " take-off " and level flight.

These advantages are illustrated in the graph shown at Fig. 22, where the horse-power available as useful thrust is shown for a fixed-pitch airscrew, a controllable-pitch airscrew and a constant speed airscrew under similar conditions of flight.

The lowest of the three curves shows the thrust horse-power available with a fixed-pitch airscrew designed to give cruising r.p.m. at 17,000 ft. with full throttle in level flight. From this curve it will be seen that only slightly more than 350 effective horse-power is available at sea level, and that the maximum cruising power is not attained until the altitude of 17,000 ft. is reached.

The intermediate curve shows the effective horse-power available with a fixed-pitch airscrew designed to give cruising r.p.m. at 10,000 ft. with cruising manifold pressure in level flight. It will be seen that considerably more power is available at sea level than in the case of the airscrew designed for 17,000 ft., and therefore it would be less hazardous to take-off with a fixed-pitch airscrew than in the previous case. A two-position controllable airscrew, however, with the high pitch adjusted to 10,000 ft. and the low pitch set for take-off and climb, would give a much better performance from sea level up to 10,000 ft., although it would have no advantage over the fixed-pitch airscrew above 10,000 ft.

The third curve indicates the effective horse-power available with a constant speed airscrew installed on the same aircraft and engine. With this airscrew maximum permissible cruising power can be used throughout the climb to 17,000 ft., whilst 18·6 per cent. more power is available at sea level than with the airscrew designed for maximum cruising power at 10,000 ft., and about 35 per cent. more than is available with a fixed-pitch airscrew designed for maximum cruising power at 17,000 ft. These figures are also true for a two-pitch controllable airscrew set for like conditions and climbed in high pitch.

It is apparent that at the critical engine altitude for cruising power—that is 17,000 ft.—the constant speed airscrew cannot make available more power than the high-pitch setting of the two-pitch controllable airscrew set for that altitude, but compared with a fixed-pitch airscrew or a two-pitch airscrew set for 10,000 ft. there is a gain of about 25 per cent. of power under these conditions.

The full ground rated power of the engine may be used for take-off by adjusting the throttle to give the maximum permissible manifold pressure and adjusting the constant speed control to give the maximum permissible take-off r.p.m. The constant speed airscrew will maintain this r.p.m., notwithstanding the increase in forward speed of the aeroplane from rest until it becomes air-borne, hence full power is used throughout take-off run and into climb. During climb the full rated power of the engine is available at all flying speeds and all altitudes by the independent control of the throttle (boost) and the r.p.m. (constant speed control), and with supercharged engines there is a marked increase in the rate of climb as compared with a fixed-pitch airscrew or a two-position controllable. At altitude power is reduced to the cruising value by adjusting the throttle to provide the specified manifold pressure for this condition and adjusting the constant speed control to provide the corresponding r.p.m. Cruising speed and top speed are considerably improved, both above and below critical altitude for cruising, as compared with performance when using a fixed-pitch or two-position controllable airscrew, but at critical altitude the constant speed airscrew must necessarily give the same performance as the fixed-pitch or two-position airscrew adjusted for that altitude.

In military aeroplanes the constant speed airscrew is particularly valuable, since it makes available full engine power in all attitudes of the aeroplane in manœuvring or carrying out military exercises and obviates the harmful effects on the engine of over- and under-speeding. In formation flying the speed of the aeroplane is controlled as usual by the throttle, but this, whilst effecting a change of power, is not accompanied by a change of r.p.m., and all evolutions which are carried out in formation can be performed without further attention to the constant speed controls.

In multi-engined aeroplanes the need for synchronisation of the engine arises urgently because of a disturbing reverberation which occurs when

the engines are out of phase. With constant speed airscrews this presents no difficulty as the adjustment and speed control characteristics are of such an order that it is possible to obtain and maintain almost perfect synchronism. Equally, such airscrews are not liable to be thrown out of synchronism by turbulence of the air or the operation of flying controls, and when once synchronised the engines can be adjusted for power without being thrown out of step.

Considering again the analogy of the motor vehicle, the foregoing description might well illustrate the case of three similar cars operating over the same gradients—the first without gearbox would have to be abnormally high powered to negotiate hills, and on the level it would require to be throttled down to prevent over-speeding. It would be wasteful of fuel on this account, and the throttle would constantly require the driver's attention. This is the case of the fixed-pitch airscrew. The second car, having only one alternative gear, could be provided with engine power to give maximum economy on the level only. In this case the low gear would enable it to negotiate a specified gradient, and only in surmounting less gradients would the combination be wasteful of fuel and need the attention of the driver to control speed.

This, in principle, is the two-pitch variable airscrew, but actually the parallel soon ceases to apply, for whilst the road vehicle would be uneconomical because of the variety of gradients it had to contend with, the aeroplane can choose its own hill and in practice is usually climbed at the most efficient angle or climbing speed.

The variable-pitch airscrew is equally efficient in climb and level flight, and if we substitute the idea of altitude and rate of climb for gradient, the two-pitch airscrew approximates more closely to the car with an infinitely variable gear.

The third car, having the infinitely variable gear, would be fitted with the same engine as No. 2, but as the gear would be adjusted automatically to the gradient (the load), the engine would continue to turn at the predetermined speed, and only the speed of the car over the road would vary. The engine would, therefore, be performing continuously at high efficiency, using a minimum of fuel and requiring little or no attention from the driver, which summary applies exactly to the constant speed airscrew.

As mentioned previously, all de Havilland airscrews are inherently constant speed airscrews, and the foregoing advantages can be realised on any two-pitch installation, where provision can be made to mount and drive the constant speed unit.

PRACTICAL CONSIDERATIONS IN AEROPLANE DESIGN

By Charles B. Baker

A LARGE number of details must be considered in connection with the general maintenance of aeroplanes in service—particularly R.A.F. aeroplanes. In past years, and until recently, ease of maintenance has been much neglected in the design stage, all efforts being concentrated on performance in the air, leaving the ground side to look after itself. The reduction of personnel in R.A.F. units demands aeroplanes that are easy to keep in flying trim, and a study of modern requirements in this respect is well worth the while of those engaged in the design of aeroplanes. It is noteworthy that the Air Ministry is giving more attention to ease of maintenance and repair when reviewing new types that come up for acceptance trials.

The items to be considered are many and varied. If an aeroplane is divided into its main sections and these sections are taken one at a time, it will be possible to sift the relevant items into chronological order. Matters connected with rigging and truing up will be found in other sections.

Slings

A fuselage without wings, undercarriage or tail unit, but with or without the engine requires some means of slinging from a crane or the ordinary lifting tackle. When the top centre plane of a biplane is built as a fixture, the sling can be conveniently attached to the main members of this and be arranged to stow away in the thickness of the plane. If the top centre plane is detachable, and also carries the sling, then the fuselage cannot be hoisted until the centre plane is rigged. It therefore seems that a sling attached direct to points on the fuselage is the best arrangement; if the aeroplane is intended for work at sea the sling must be a permanent item of equipment and can be designed to pass through or round the top centre plane. It is important for this work at sea that the sling is easily accessible and able to be prepared for use with no danger of failure. It must be remembered that the actual hooking on when coming alongside a ship in a seaplane is done by a member of the crew other than the pilot, so ways and means must be provided for the man to get from his normal station to the sling in safety without treading on the head or shoulders of the pilot or falling overboard. If he can

reach the sling stowage quickly and remain there sitting or standing with safety on the top centre plane, well and good, for in that position he is not likely to be blocking the pilot's view.

Aeroplanes not used for work at sea can have detachable slings. These should be plainly marked as to correct method of use and the attachment points on the fuselage should be clear of all secondary structure and easily accessible on removal of cowling panels.

Trestling Points

A matter closely allied to hoisting slings is the provision on the fuselage of definite trestling points. Too often are these omitted, with the result that fuselages are rested direct on the structure members and not always at the most suitable localities. The fuselage structure is invariably surrounded by fairing formers and such-like secondary material which is not easily detached and consequently is liable to become damaged when wedging-up on a trestle that does not fit. The feet of the trestle should preferably be out of the way of undercarriage attachment points so that it will not interfere with any work which may be necessary on them.

The rear end of the fuselage should have its trestling point apart from the hand lifting points, to avoid misuse of both points. The location of the rear trestle needs to be fairly well forward in order to leave clear the whole of the tail unit. Work on tail skids or wheels, stern posts, trimming gear, etc., is much hampered by the close proximity of trestle legs.

Handling

The points provided at the rear end of the fuselage for handling purposes are, as a rule, most inadequate and of poor design. It is a simple enough matter to calculate the number of men that will be required to lift a given weight allowing for personnel of average strength. When there are not enough hand grips provided, then other parts are gripped that will give any sort of hold, resulting in stresses being imposed on tail planes, stay struts, etc. for which they were not intended. The hand grip should not be so placed that when in use the lifter's arms or body tend to purchase against the fuselage sides. Such pressure is liable to deform the fuselage fairing. If the hand grips can serve the dual purpose of lifting and holding down, so much the better. Leaning over the tail plane with the whole weight of the body while the engine is being run is not good treatment.

Footsteps

The provision of footsteps seems to be made in a most indiscriminate manner. Very often it appears that when the aeroplane is finished the designer has come along and said, "Now where are we going to put our footsteps?" Perhaps he has then decided where they *ought* to go but

found innumerable difficulties in the way and in desperation has had to put them wherever they could be accommodated without upsetting the already finished structure. The result is that the crew have to fall back on some remote ancestral instincts to enable them to get aboard safely when encumbered with flying suits and parachutes. The first step from the ground has to take the greatest strain, so it should be made very strong and accommodating. Hand grips that come easy to hand are also worth providing, as they relieve other fragile parts from misuse. The size of footsteps or footholes is important, too, for the flying boot is considerably larger than the normal footwear. When footsteps take the form of footholes in the side of the fuselage the openings should be covered with spring flaps or canvas bags to keep out dust, sand, draughts, etc. As a rule it is necessary to have steps only on one side, though for specific purposes they may be required on both sides.

Ballast Weights

Ballast weights are essentially a fuselage problem. The question of their stowage is quite a simple one, yet so often is it badly understood. The modern requirement is that besides a mounting for them in the "live" state there must also be a stowage to enable them to be carried "dead."

"Live" and "Dead" Stowage

The "dead" stowage must obviously be somewhere close to the C.G. of the aeroplane. The "live" mounting is usually fairly well aft in the fuselage. Both stowages should be arranged so that weights can be shipped and unshipped singly.

Many stowages in the past and even to-day require the weights to be attached in batches of six. Now one weight weighs roughly 17 lbs., so that the fitting of a set is hardly a single-handed job. When the stowage is beneath the fuselage it is almost impossible to get a batch of weights in position. This results in the weights being left behind or tied up somewhere in the back cockpit. If designers want their aeroplanes to fly in correct trim on all occasions, they must make the stowage of ballast weights a convenient task.

Inspection Panels

Inspection panels are necessary in all covered structures, and in many respects the more of these there are the better, provided they fit well. With a rigidly braced fuselage, it is not essential to have access to all parts, but it is convenient to have an easily opened portion wherever there are moving parts located, such as controls, trimming gear, tail shock absorbers, etc.

Light metal or fabric-covered panels fastened with turnbuttons answer very well. Such panels should be dustproof and in the case of

seaplanes, sprayproof. The best way of preventing corrosion by sea-water is to keep the water out. Zip type panels are good when new, but are liable to get clogged with dope or otherwise damaged; it is not easy to get a well-shaped opening with this type of fastener. Cowling panels are dealt with in the section on Engine Installation.

Pilot's Comfort

A point that is often overlooked in the design of fittings and components for the pilot's cockpit is that of allowing plenty of clearance for the pilot's hands. Pilots do not always wear gloves and they will soon become irritated with any mechanism that carves little bits off their knuckles and fingers. Let the designer get into the pilot's seat and note the improvements that could be made by perhaps fitting a clip the other way round so that the bolt is out of the way.

Fittings and projecting brackets should have smooth rounded edges instead of sharp corners. The localities chiefly affected are those in the neighbourhood of throttle levers, trimming handwheels, hand fuel pumps, primer pumps, bomb fusing levers, etc., in fact, any region where there is a hand-operated control.

ENGINE AND ACCESSORY INSTALLATIONS

In this section reference to matters solely concerning the engine will be limited to those met with in the course of general daily maintenance, more particularly those items which are as much the concern of the aeroplane builder as of the engine manufacturers.

Ring Cowling

Now that we are using N.A.C.A. cowling and Townend rings more generally, the matter of accessibility of the radial engine becomes increasingly difficult but very important.

Cowlings are invariably set as close to the cylinders as possible so that valve tappets and overhead plugs are at once rendered absolutely inaccessible. To get at these, it is necessary to remove the cowl ring. Now a deep or long ring usually weighs quite a lot and is very unwieldy, requiring two men at least and sometimes more to set it in position. This is the case when the cowling is in two pieces, joined together on a fore and aft line.

A Suggestion for Designers

It should surely be possible to make the ring in several sections although this will increase the number of fastenings. Offset against this is the added advantage of being able to remove only one portion for local adjustments to the engine. It may be argued that too many fastenings will reduce the value of the cowling through interfering with the smooth

flow of air. Here is a chance for designers to exercise their ingenuity in producing a smooth flush fastener that is also of the quick release type.

Straight Cowling

The cowling for a liquid-cooled engine and the in-line air-cooled engine can be arranged as panels attached to a permanently fixed frame. Panels have of necessity to be of thin-gauge metal to keep down the weight, but at the sacrifice of rigidity. Large flat panels will pant unless stiffened up and will always suffer damage from being constantly handled.

Panel Sizes

It may be cheaper in the long run to use smallish panels over the nose portion where most vibration and handling takes place, whilst further aft in the region of tanks and centre fuselage, the large panels will be found to serve satisfactorily.

Airscrews and Spinners

Maintenance of airscrews has its points peculiar to each type, though all types have the common need of periodical checking of track and the main hub bolt fixing. Wooden airscrews call for more frequent attention owing to the possibility of shrinkage of the material, unless attended to shrinkage at the boss can lead to serious trouble. If the boss is too tight a fit on the hub, the effect of hot weather can shrink the wood sufficiently to crack it. This point should be remembered on aeroplanes that may be flying to warmer climates.

A Word *re* Clearances

Clearances that hold good for the British Isles will need checking in warm, dry countries. Hub bolts require similar attention in like circumstances.

Metal Spinners

Metal spinners on wooden airscrews require careful attention when they are of the type having a front and back plate clamped to the boss. In this case tightening up the hub bolts to take up shrinkage has the effect of squeezing the two spinner plates together.

This unnatural pressure will distort the spinner body resulting in a tendency to crack the metal.

How to Allow for Shrinkage

Care should be taken to see that the original spinner dimensions are maintained by inserting a packing disc of three-ply, or other flat and not too soft material between the boss of the airscrew and the front or rear spinner plate before pulling up the bolts when shrinkage demands this.

Tracking of Airscrew Blades

Airscrews with detachable spinners should have each component clearly marked for assembly purposes in order not to upset balance through the spinner being fitted half a turn out. A check must always be kept on the tracking of airscrew blades. An $\frac{1}{8}$ in. out at the tip should have no adverse effects, but a greater amount may cause unnecessary engine vibration, particularly with metal airscrews.

Starting and Doping

Now that the Hucks-Starter is becoming obsolete, it is essential that we should have good, foolproof starter systems for our engines. Aeroplanes that are not large enough to warrant the carrying of battery and motor for electric starting must be content with hand turning gear of one kind or another.

The Inertia Starter

Whether it be an inertia starter to wind up or the direct drive to the engine, the handles should be so placed that the person whose unhappy lot it may be to turn them can do so with the least discomfort and unnatural body distortion.

It is best if the operator stands on some part of the aeroplane rather than on the ground, but he requires some well-placed grip for his "idle" hand so that he can get a good purchase on the turning handle. The handle needs to be low in relation to the man's body, allowing him to use his bodily weight. A good non-skid footing is also necessary.

Two Starting Handles are Better than One

Though one handle may be sufficient drive it is as well to provide additional accommodation for a second, for this will lighten the task in extremes of hot and cold climates. Starting handles placed in the interior of cockpits and cabins may gain in compactness and neatness, but may be a nuisance when the aeroplane is loaded up with full equipment and crew. The outside position for the handle with the man on the aeroplane, besides giving a good purchase, is satisfactory for use on seaplanes.

Notes on Priming

Engines invariably require priming before the initial start. Each type of starting system usually has its own peculiarities which have to be learnt and always dealt with in the same manner in order to be reasonably sure of a good start-up.

The Starting Instruction Plate

To help personnel new to a type, it is worth while providing an instruction plate giving full details of the whole starting procedure.

In different kinds of weather—hot and cold—there is usually a variation in the amount of priming needed. Similarly, there is different priming procedure for hot and cold engines. All this should be detailed on the instruction plate.

Priming Pipes—A Recommendation

In many types the pipe from the priming pump to the engine connection is made of copper and, as a rule, is of small diameter. Such pipes break sooner or later. The result is not damaging to a large degree, but it does mean that the induction system acquires an air leak which it was not intended to have ; and there is the inconvenience later on when a start-up is attempted with the priming charge being shot anywhere but into the right quarter. Priming pipes should certainly have a flexible length at the engine end.

After the Overhaul

In connection with the first start after overhaul, when the pistons have been removed and refitted, it should be appreciated that the normal procedure is most unlikely to answer at all satisfactorily. Special measures must be adopted in view of the possibility of dry cylinders and leakage past piston rings that may not be a perfect fit.

If this is the case the cylinders will charge up with an excessive amount of air on the induction stroke and will be weak on compression. Priming, especially overpriming, will tend to make matters worse through the liquid fuel washing away what little oil seal there may be on the cylinder walls.

To Facilitate Starting

Undoubtedly the best procedure is to remove a sparking plug from each cylinder and give the cylinders a good priming of oil with a spray syringe. After a few turns of the shaft to distribute the oil over the cylinder walls and pistons, the engine should then be primed in the usual manner for the type.

Radiators and Condensers

When liquid-cooled engines are used, there are some points about the radiator or steam condensers which are worth considering. Radiators and condensers are very heavy components and in service it is likely that they will have to be handled quite a lot. How often does one see one of these that can be lifted about without fear of its being damaged ?

A Suggestion

It should surely be possible to incorporate in the design some handhold for those that will have to lift it about. Probably more damage is

done to radiators during handling and transport than throughout their life on the aeroplane.

The attachment of radiator or condensers to the aeroplane needs to be simple and straightforward with hose connections that are easily accessible. When there is a hose joint tucked away in some corner, sooner or later there is going to be trouble through bad fitting or through failure to renew when unserviceable. The simpler the design the better chance they have of being properly maintained. Condensers that are to be carried attached to the surface of the top plane could do with some careful study.

The facilities and conditions of the average flying unit are far removed from those existing in the manufacturer's shops and when a heavy component like a surface condenser has to be removed or fitted to a top plane, it is a case of "all hands on deck." If the condenser is made with convenient points for handling and is placed where it can be approached from a step ladder, then it stands a chance of being moved about without damage to itself or to other parts of the aeroplane.

Condensers and radiators should have the test pressure noted on an instruction plate affixed to the component.

Water Tanks

Water header tanks are always placed high up on the aeroplane, yet the designer often overlooks the provision of some means of getting there. If the aeroplane is away from its base a step ladder is not always available and if it is a seaplane on the water a ladder is useless whether available or not. Therefore footsteps are required on the aeroplane and preferably giving a direct route so that water cans can be handed up and down without being rested *en route* on main planes and cowling panels.

Tank Vents must be Rustproof

Water tank inlet and outlet vents sometimes take the form of spring-loaded valves. The moving parts of these valves should be made of non-corrodible materials to ensure freedom from sticking. A seized-up inlet can be the cause of broken seams or even tank collapse when contraction sets in on cooling.

Engine Controls

Throttle and ignition controls are almost universally of the push-pull rod type. On large aeroplanes the distance of this transmission may involve the use of several layshafts with consequent pin joint attachment of the push rods. Unless well designed, wear will quickly occur on pins and fork ends, resulting in lag and backlash in the system.

On twin- or multi-engined types this will mean that the throttles will get out of synchronisation. Large bearing areas should be provided on all pin joints, and sufficient metal on plug ends to permit reaming out

and fitting oversize pins. Such provision in the first place will save the operator time and money subsequently on replacements.

Fuel Tanks

So many considerations have to be taken into account in the design and positioning of fuel tanks, that it is hardly possible to achieve the perfect installation. However, not the least important considerations are those of maintenance and service, the demands of which could bear a little closer study.

Small structures have to carry the fuel supply split up amongst two or three tanks owing to restricted room. There are advantages in this in that the tanks are small and easily handled or replaced, and replacements are comparatively cheap. On the other hand, they need more piping and mounting fittings. Large single fuel tanks are simpler to mount and manufacture, but can be awkward things to handle when replacement is necessary.

Tanks are fragile things and will not bear rough handling, therefore the moving of them into and out of their mountings should be made as easy a task as possible. Large tanks especially should be so disposed that they will pass through the bottom of the fuselage. Handling a tank in or out sideways invites damage unless it be a small tank that is easily manœuvred. Large tanks should also be provided with something by which they can be gripped so that all the work has not to be done from underneath where visibility is poor.

Tanks can be made to retain their slings or harness, this being fitted prior to placing the tank in the aeroplane. The straps of the cradle can then be used as lifting points.

Quick release pins are preferable to bolts for securing the cradle or sling to the actual mounting.

Wing tanks, placed high up, must have hand grips of some kind otherwise they are sure to be dropped. It is important, too, that the crew have ready access to the filler caps of wing tanks.

Refuelling Connections

Refuelling cannot always be done by Bowser pipe so it must be remembered that a funnel and can may be used and accommodation provided for these in the region of filler necks. On large aeroplanes it would be convenient to have a refuelling connection below the fuselage with a semi-rotary hand pump to do the work.

Drain Pipes and Cocks

Drain pipes should be fitted to all tanks, the pipes to have their individual cocks and to discharge to a point outside the aeroplane. The size of vent pipes is important especially in a system comprised of several interconnected tanks.

A Point to Watch when Refuelling

Such a system probably has one filling neck and possibly one small vent pipe. When refuelled with the modern electric Bowser the fuel goes in quicker than the air can get out, resulting in air pockets being formed in some more distant part of the tank system. This trapped air may not have time to escape before the filler neck is overflowing and one can be misled into thinking that the tank is filled up. Unless the fuel is checked again before flight, there might be serious consequences.

Up to recent times filling was always done by can and this vent problem did not arise. Tank filler caps should always be marked with the capacity of the tank or of the system if one neck serves the lot.

Fuel Gauges and Filters

Fuel gauges are still far from being perfect, but they are essential fitments, and should register when the aeroplane is at rest as well as when it is flying. Fuel filters must be in easily accessible positions otherwise they are liable to be neglected. Preferably they should be where they can be reached by a man standing on the ground and be close to an inspection door or cover which is suitably labelled. They should be so placed in relation to the shut-off cock that an appreciable amount of fuel is not wasted every time that the filter is opened up.

Instrument Panel

Modern flying instruments are fairly reliable mechanisms, but at some time or other they have got to come out, if not for replacement, then for calibration, so when designing the position and layout of the instrument panel, this point should be remembered. So often do we find the securing screws buried far beneath a maze of pipes and leads which themselves are crowding in behind structural components. Panels cannot always be large owing to limitation of space and dials are necessarily crowded owing to multiplication of instruments, but it should be possible to leave a little elbow room *behind* the panel where all connections have to be made. Magneto switches and air speed indicators particularly need to be accessible; the corners of the board can be used for the less used items such as heating switches, compass card, instruction plates, etc. The compass position is usually specified by the customer, but the designer can arrange that it is not so crowded that the correcting magnets cannot be easily inserted.

Instruments with pipe connections should have adequate spanner clearance around the coupling nut. It should be realised, too, that someone will have to get at such nuts to lock them with a piece of wire.

MAIN AND TAIL PLANES

General Items

Tail planes can, as a rule, be handled with ease, but the larger components—main planes—are unwieldy and require hand grips at the root and tip ends for use when assembling or moving about in stores. The

root fittings are usually sufficient at that end to give a hand-hold, but the tips should be provided with definite grips otherwise tip tubes will be damaged. Tip grips are useful for ground handling the aeroplane, and if a seaplane similar hand-holds do good service on the top plane when manœuvring alongside a ship. It must be borne in mind that planes, as units, are invariably rested on their leading edges, so this part must be able to stand any such loads without crumbling.

Walkways on planes get rough treatment and must be able to stand up to this if the contour is to be preserved. Where the contour is most likely to suffer is in that portion between the leading edge and the front spar on the top surface of the plane. Pushing the aeroplane about on the ground accounts for a lot of deforming of the aerofoil shape, while washing down by non-technical labour can also have a bad effect. Small nose riblets become flattened, though it is not always noticed that this is happening, yet the pilot will feel the effects at slow speeds and in extreme cases will wonder why the aeroplane suddenly "falls out of his hands." To guard against this damage occurring to planes the top booms of riblets should be made stronger than is necessary for flight loads.

Electric Wiring

Electric wiring in planes does not deteriorate to any marked extent and can be confidently expected to serve without fault until such time as the fabric is stripped for recovering. Leads from the fuselage should connect with the plane wiring by means of terminal points in the plane root and should not be integral with the plane wiring terminating only in the fuselage. It is the exposed root portions that will need renewal first and this can be done economically and without trouble if the lengths are short.

Corrosion

Corrosion of the structure is not incidental if care is taken to keep the salt water out when being used as seaplanes. Lower planes are more prone to being wetted than top planes, though the latter come in for their share of water in the vicinity of the slipstream. There are so many small openings in planes through which water will find its way, and once inside no amount of paint or anti-corrosive treatment will check its ravages, save perhaps petroleum jelly. All openings, therefore, should be properly sealed and the wing vented by a special vent system which can terminate in a guarded part of the fuselage. A wing that is so sealed will provide considerable buoyancy, so that the arrangement is worth considering for sea-going aeroplanes on wheels.

Wing Folding

The quick, easy folding of the main planes on aeroplanes in use on aircraft carriers is a most essential feature. Speed in deck handling is all-important, for it is necessary to have the main planes folded by the

time the aeroplane has been wheeled on to the lift. Jury struts are inconvenient and apt to become a nuisance and a hindrance. Planes must dispense with these and yet fold back and stay folded without getting out of truth. Root locking pins should be arranged to withdraw by an operation performed from the deck or the cockpit to save unnecessary climbing up on to the aeroplane.

When the planes are in their folded state there must be room for the crew to get in and out easily and to load or unload their equipment. The folded wings should not cover up inspection points nor hamper refuelling operations. When below deck the aeroplanes are packed tightly and there is little chance of "spreading" wings to allow normal access to the fuselage and cockpits. It is convenient if the aeroplane, when folded, can be moved about on its front and tail wheels without fear of fouling the wing tips on the deck.

Some means of locking the planes in their folded condition is necessary to prevent swinging, due to the movement of the ship. Also, it must be possible to affix bombs, etc., to the planes when they are folded with no danger of adverse effects while the wings are being spread.

Tail Incidence Gear

The fact that there are moving parts in the tail plane anchorage calls for careful design of the joints in question to obviate any tendency towards sloppiness. It is not a good thing to have tightly fitting bolts as this would make the operation of the trimming gear too stiff. Large aeroplanes get round it by having fixed tail planes and elevators that can be trimmed by means of servo controls, but many smaller craft continue to use the movable type of tail plane. It is important to have good inspection and lubrication facilities at all relevant points and the actual tail jack mechanism should be readily accessible for cleaning purposes. The worm gear is necessarily a good working fit which means that a few grains of fine sand will soon produce a first-class seizure. Where there is sand about, grease will certainly collect it, so it is preferable to keep exposed parts dry, occasionally lubricating with some fine oil. If possible a special cover should be provided for the jack, as this allows grease to be used without fear of it being transformed into a grinding paste. The hinge points of the tail plane could conveniently be made extra large in bearing areas as well as in the surrounding material. Large bearing surfaces take longer to wear and when they do eventually, the extra metal provided around the holes will enable oversize pins to be fitted.

UNDERCARRIAGES

Wheels

The aeroplane manufacturer has little say in the construction of landing wheels, but he has to arrange the manner of their mounting on his aeroplane. Wheels with plain bearing bushes get a lot of end play on

the axle through wear of the bush and the stop collars. With this type it would be well to have the bushes end-bearing on to floating collars, so that when the play becomes excessive, new collars could be fitted instead of the more expensive stop collars or end fittings. Oversize floating collars would naturally be required. Wheels that are fitted with Timken type races could, with advantage, have the instructions for adjusting stencilled on the wheel disc or brake drum. It is important, too, that the correct tyre air pressure is known for the particular type of aeroplane to which the wheel is fitted. The aeroplane maker decides this, so he should have it marked on the wheel disc or nearby component for the information of the ground engineer.

All wheels need a jacking point alongside. This should be a fitting specially designed for the job and it should not be left to the rigger to select any spot that looks convenient. If one wheel of large size is being jacked the other should be wedged at the axle. Omission of this precaution may result in the aeroplane rolling on the free tyre, causing the jack to slip.

Oleo Legs

Oleo type shock absorbers and dampers are fairly common fitments, but there is a lack of standardisation in their design. Each type has its own particular setting and maintenance features which are liable to be confusing to the man who may have to attend to several types. Full instructions for filling and setting should be given on an instruction plate attached to the leg, then there can be no mistakes. Instructions should include the kind of oil to be used, method of filling, the correct air pressure, method of test, the valve setting for various loadings and all relevant information. Though variable settings are provided by many manufacturers, it is often that full advantage is not taken of them through mere ignorance of their adjustment. It is a fact that different surfaced aerodromes require different oleo settings to get the best results. A "hard" setting that suits a soft sandy aerodrome can be responsible for buckled wheels on a hard or stony surface. Deck-landing aeroplanes can gauge their settings to a fine degree as they are landing always on a surface of uniform hardness, and by getting the oleos adjusted just right they can avoid trouble of many kinds.

Float Chassis

Aeroplanes designed for use as deck-landing aeroplanes convertible to seaplanes require above all things the ability to be changed over from one to the other with the least possible delay. This will be an essential requirement in war-time. The nearest way to achieve this end is to arrange things so that the complete float chassis can be assembled apart from the aeroplane and then offered up as a whole to the fuselage when required. In this arrangement time is saved, as part of the crew can be preparing the floats while the others are detaching the land chassis.

Coupling up the float struts to the aeroplane is simplified if the fittings to take them are already in place, and if the land undercarriage fittings and bolts can be used also for the sea chassis so much the better.

Rigid bracing for the float undercarriage is preferable to wires; the latter not only have to be trued up and watched for stretching, but also suffer from corrosion troubles. Water rudders operated by cable are not perfect mechanisms, and require close attention to get the best possible results. Owing to the numbers of pulleys involved, the movement is stiff, and the cables invariably stretch and corrode. All moving parts must be kept free and well greased. Aeroplanes fitted with hydraulic or pneumatic brakes sometimes have their brake systems adapted to operate the water rudders as an alternative. In the case of pneumatic operation the air system must be absolutely leakproof to conserve the air supply. Constant attention to details is essential.

Floats themselves should be interchangeable, and it is an advantage if one float of a twin-float assembly can be changed without having to dismantle the whole undercarriage. Adequate mooring eyes and cleats are essential fitments and a stowage for a towing or mooring bridle *in situ* is an advantage.

Float tops must be strong enough to bear being walked on and must have a non-slip surface ribbing.

Footsteps must not be forgotten for the use of the crew getting into and out of the aeroplane. These can be built integral with struts to avoid separate fitting.

Large inspection hatches are required in each compartment so that minor repairs to any part of the float can be made without having to remove part of the skin. Any special maintenance treatment should be stated on a permanently fixed label, such as instructions for correct anti corrosive precautions, draining points, etc.

Tail Skids and Tail Wheels

The tail skid nowadays needs little attention, its only trouble being that of wear. The shoe, therefore, should be of ample dimensions and both easy and cheap to replace. Sometimes skids or their shock absorber break; it is well then to have an auxiliary bumper under the fuselage to protect the sternpost in emergencies.

Tail wheels work best when at their correct pressure. This should be stated somewhere on or near the wheel. Easy removal of the wheel from the frame is advantageous for the purpose of puncture mending.

CONTROLS

The main flying controls of many aeroplanes continue to be designed to employ cables as a means of transmission. Cables certainly simplify many matters and they are also comparatively light, but they can lead to many troubles unless proper precautions are taken both in the design

stage and in subsequent service. Undoubtedly the best arrangement is that in which all cables have a direct unfettered run with bell cranks to transmit at the corners. If pulleys are used they need to be of large diameter and should rotate on ball bearings. Where the latter are employed they must have dust covers to keep the lubricant in and the dirt out. Inspection doors must be available at all pulley positions where these occur in otherwise inaccessible places.

Fairleads for cables are best made of fibre, so arranged that the fibre can be removed and split to allow a made-up cable to be threaded through. Fibre fairleads are best left unlubricated, as in that condition they do not collect sand and grit which, with grease, forms a potent grinding paste.

All components in the pilot's control system should ride on ball bearings—this applies also to push-pull rod joints. Where push rods have plain bearings they should be of large area and preferably of the detachable bush pattern. Where joints have removable bushes they can be kept a good fit by renewal of the bushes when they wear. If the joint is of the plug-end-cum-bolt type it is an expensive matter to change such components besides being inconvenient and more often than not the joint is left sloppy. All ball races in the system require guarding against the ingress of sand and dirt. The guards also prevent the escape of the lubricant.

Hinges of ailerons, elevators and rudders wear rapidly if the bearing areas of the pins are small. Whatever type of hinge is used it should preferably have a greasing nipple or other means of lubricating. This will ensure that the lubricant is forced well into the bearing surfaces. It is most important that only non-freezing lubricant is used in the control system.

Cable sizes should be stamped on a tag affixed to the cable eye, in much the same way as the inspection stamp is carried. There is no reason why the size mark should not also be on the inspection tag. This precaution is to prevent wrong-sized cables being put in when a change is being made. The 5-cwt. difference between cables can easily be misleading even though a person may be handling them frequently.

An undersized wire can lead to serious consequences when it stretches. The importance of the whole matter of slack or sloppy controls cannot be over-stressed when it is realised that it is such conditions that encourage the phenomenon known as tail flutter or wing flutter.

Experience shows that with tight controls, *i.e.*, controls in which no backlash can be felt, tail or wing flutter is unlikely to occur ; but when there is movement possible in elevators or ailerons without there being a corresponding movement of the control column then at some position of the centre of pressure they will flap like a flag at a flagstaff. If allowed to persist this flapping will assume alarming proportions and will shake the control column even against the pilot's hold thereon. At a certain stage of the flapping reversal occurs and the tail plane or wing begins to

rock. If they are stiff enough to resist the flutter or to check it the tail plane or main plane will stay put, but if they are weak or have sloppy attachments they might conceivably break. The incipient flapping of the elevators or ailerons can be stopped by an alteration in the centre of pressure, that is, by a return to normal flight. Mass balancing of controls may be a deterrent to flapping at certain speeds, but it is a known fact that controls have fluttered, even though mass balanced in correct fashion.

The most practical method of guarding against flutter is—as stated previously—to keep the control system tight, and designs incorporating joints that will not wear too easily and cables strong enough to resist stretching provide a deterrent to trouble of a most serious kind.

RIGGING

In the days of wings that had a flat under surface the usual procedure when rigging was to place the straightedge under the wing and take a reading from an Abney level. Nowadays wings are becoming almost universally bi-convex, and this method of checking is impossible without packings against the spars or using straightedges specially shaped to suit the contour of the plane. It should be possible to rig and maintain all types of aeroplanes with no special implements beyond the ordinary parallel straightedge and a straightforward spirit level. This could be done if the designer provided on his wings small fixed straightedge posts or rigging blocks so dimensioned that when a straightedge placed across them gave a level reading the plane would be at its correct incidence or dihedral, as the case might be. This to occur, of course, when the fuselage is in rigging position. Such rigging blocks need to be on the upper surface of planes in order that the straightedge can be rested on them. If placed below the plane the straightedge has to be held in position, which means an extra man on the job. Also, when underneath, the spirit level can only be placed on the projecting end of the straightedge, whereas the proper place for it is in the centre. The same thing applies to tail planes. It is only necessary to find the normal position. Range of movement can be checked against the incidence indicator which will have been calibrated correctly in manufacture and checked on inspection by means of an Abney level.

The fuselage levelling points should be similarly arranged and should be accessible, if possible, from inside the aeroplane. It should be simple enough to provide stubs from the main structure to carry a straightedge clear of all fittings and projections.

For rigging or setting controls it would be convenient to have some lock-pin arrangement by which the control column and rudder bar could be fixed rigidly in their proper centralised positions. The locking means can be completely detachable if desired, so as to prevent any possibility of their coming into use when not expected.

EQUIPMENT

The placing of equipment in service aeroplanes is usually decided upon by specialists in the various subjects. However, their requirements can often be improved upon and supplemented if some thought is given to the subject by the designer. A few points only are given here, but many more could be discovered if a thorough search were made of the aeroplane.

There is not much latitude allowed the designer in the positioning of the fixed machine guns, but he has full control of their detail mounting and the ammunition box arrangements. Guns need to be accessible both for adjustments *in situ* and for easy shipping and unshipping. The ammunition box especially requires to be mounted where it can be handled from outside the fuselage. There should be quick release fittings holding it in place so that an empty box can be replaced by a full one with the least possible delay. Boxes that have to be filled while still on their mountings are a nuisance generally and in times of emergency are a serious setback to rapid servicing.

Where these are still employed the installation of bomb control wires could be improved by having in mind the fact that some day they will need renewing. Wires should not be buried more than necessary as their life will be longer if they can be properly inspected and looked after.

Electrical bomb release systems are not referred to in these remarks, which apply only to the direct pull-off installations. Though electric releases are now more in vogue, the fusing of the bombs is still sometimes done by pull cables.

Drinking water tanks have to be carried on desert flying aeroplanes and also some others, but on the former type the water is needed more often when on the ground than while flying. For this reason it is convenient to have the tap located where it can be got at from outside *viâ* an inspection door. It must be possible, also, to draw water from the inside of the aeroplane. To facilitate filling, the tank must be portable and have a simple mounting attachment. It should be realised that while being replenished and installed, etc., the tank comes in for a good deal of knocking about, so it must be designed to withstand rough treatment. When unloading after the journey the tank will as likely as not be dropped over the side on to the ground along with the rest of the movable equipment.

Stowages are provided for most things likely to be carried in the aeroplane, but there are usually a fair number of oddments that have to go in as best they can. As all loose articles must be tied down, it is not surprising to find the back cockpit choked with impedimenta. What is needed for the miscellaneous equipment is a big canvas bag or holdall which can be closed securely by zipp fastener or other means and then strapped in place to specially provided anchorage points. When not required the bag could be left behind. Such things as wheel jacks and

screw pickets all have to be carried, and often there is no special stowage provided, chiefly on account of their varying shapes and sizes. Screw pickets are unshapely articles to have loose about the cockpit floor.

Stowage is provided for tools as a rule, but probably the extent of this is a box fixed to the floor well out of the way. Tools are needed on the ground, not when flying, and a stowage that can be got at from outside would be a welcome feature. A small compartment could be arranged in the wing root with advantage, where the carrying load would have little effect on trim.

Now that aeroplanes have retracting undercarriages, it must be remembered that such mechanism needs testing out on the ground fairly frequently.

Slinging points are definitely needed for all aeroplanes with this type of chassis, and it would be as well for the manufacturer to supply the sling, which can be of the detachable type, to be kept in the hangar.

In connection with the hydraulically-operated retracting undercarriages, it is essential that the correct method of bleeding the pipe lines is understood. To obtain proper working of the system all air must be excluded. After any portion of the line has been dismantled and refitted, the first duty is to bleed that particular circuit. Bleeding consists of pumping fluid through the lines and allowing it to flow through the special bleeding orifices provided at each operating unit. Any circuit that is in parallel with that under attention must also be bled at the same time, whether the line has been broken or not. The bleeding orifices are shut while a free flow of the fluid passes through them. As the hydraulic fluid may be of the kind which is a free paint solvent, it is important that the waste fluid is led away clear of the aeroplane structure. Special tools are usually provided for this operation.

WIND-TUNNELS

By Wing-Commander Vernon Brown, M.A., A.F.R.Ae.S.

AMONGST the early pioneers of aviation many undoubtedly approached the problem from a scientific aspect. Nevertheless, the advance science had made in the study of aerodynamics in the pre-flight days was so limited that the subject was essentially a practical one in which the would-be designer could hope for little, if indeed any, help from the scientist. Once flight had become an actual fact, however, the subject of aeronautics immediately assumed a new importance and began to receive greater attention. The old theorems enunciated by the mathematicians regarding the motion of bodies through air or water had rarely been capable of any clear proof and full-scale experiment was usually impracticable or dangerous. Most of the early enthusiasts could therefore progress only by a method of trial and error—the error too often proving a fatal one.

The Problems to be Solved

What then are the main problems that must be solved ? Firstly, they deal with the forces which act on an aeroplane during its motion through the air and, secondly, with the structure of the aeroplane itself. It is with the first of these that we are now concerned. What in fact are these forces, in what manner do they act and what is their magnitude under given conditions ? How can one discover the relation of their reactions, not only to the kind of motion being considered, but also to the shape of the body to be designed ? Nowadays one is so accustomed to hear of vortices, of eddies or of the effects of streamlining that the meaning of such terms are taken for granted, but in what manner can that meaning be readily demonstrated ?

The answer to such questions lies in the use of the wind-tunnel.

It is clear that mechanical difficulties must generally preclude the making of full-scale experiments to investigate the aerodynamical characteristics of a new design but one cannot imagine to-day the flight-testing of a new type of aeroplane of unknown features without some assurance regarding its probable behaviour. The experimental work will obviously be much simplified if it can be carried out on small models held stationary in a current of air instead of being moved at high speeds through the air. The use of such an apparatus as a wind-tunnel will render this possible if one pre-supposes that it does not in fact matter whether a model moves through still air or is so held in an artificially produced wind stream. So long as this wind stream is steady in velocity one may say that this is actually the case. The degree of precision,

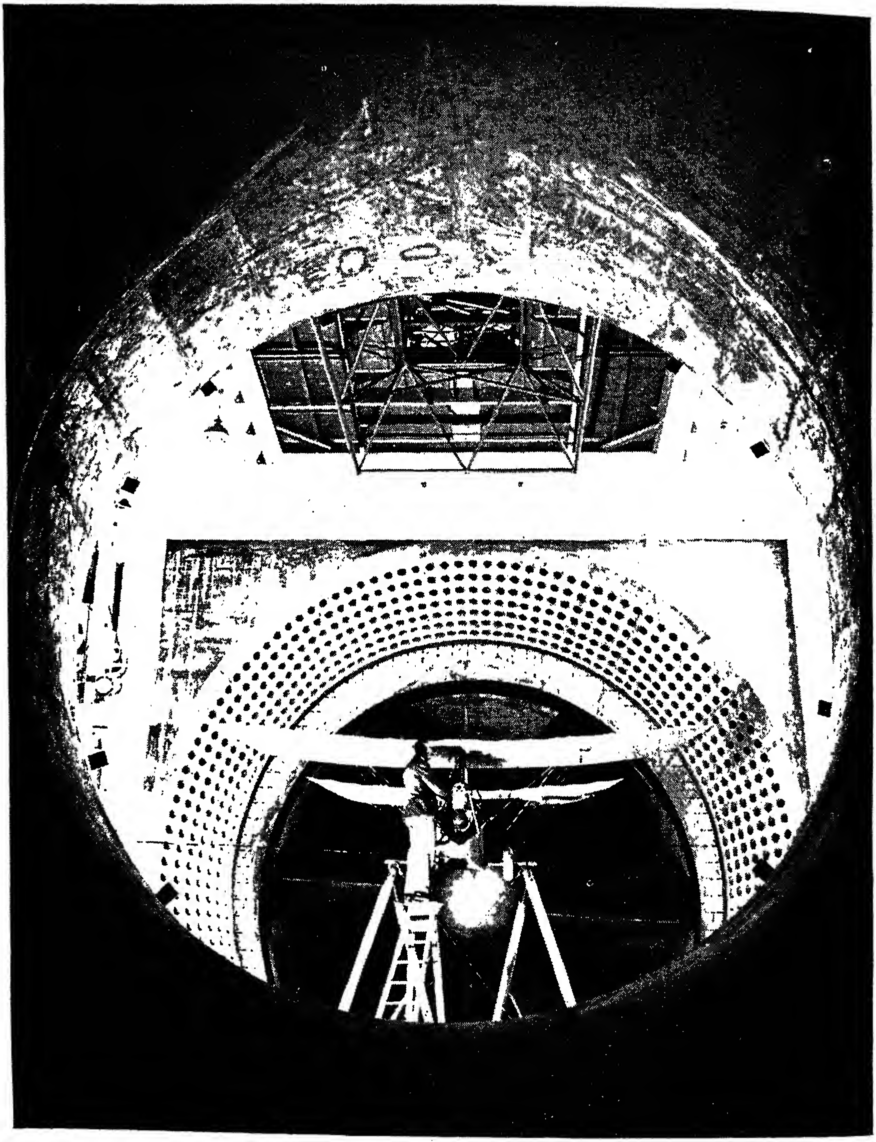


Fig. 1.—FLYING FLEA IN THE FULL SCALE WIND-TUNNEL AT ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH.

however, to which the model is made to resemble the full-scale that it represents is, of course, an important factor.

A wind-tunnel then is a device in which models of aircraft or other

bodies can be mounted in a steady and uniform air stream in order to make it possible to study the aerodynamic forces which arise as the result of the relative motion between the air and these bodies.

History of Wind-Tunnels

The history of the beginning and development of the wind-tunnel is interesting.

In 1759 John Smeaton read a paper before the Royal Society in which he is reported to have said : "In trying experiments on windmill sails, the wind itself is too uncertain to answer the purpose ; we must have recourse to an artificial wind. This may be done in two ways, either by causing the air to move against the machine, or the machine to move against the air." He went on to examine these possibilities and knowing no way of achieving the former plan, devised a whirling arm to effect the latter. It is curious that this method, *i.e.*, of mounting the body under observation at the end of a long arm carried round in the circumference of a large circle, should have continued in use for so long—for it is used for certain experiments even to-day. But to F. H. Wenham, the founder of the Royal Aeronautical Society, must be given the credit for inventing the first wind-tunnel. In the year 1871 he demonstrated his apparatus at John Penn's Engineering Works, in Greenwich. It was constructed of wood and was of 18-in. square section and approximately 10 ft. in length. The air current was created by a steam-driven fan and the velocity—measured by a water gauge—registered up to 40 m.p.h. By means of a balance it was possible to measure the lift and drag of flat surfaces at various angles, and although the device was obviously somewhat crude, the results, in the form of tables, were widely used for many years. This, then, was the forerunner of the wind-tunnel as we now know it.

The next tunnel of interest was made by Horatio Phillips—another Englishman—in 1884. The noteworthy feature in this device was the creation of the airstream by means of a jet of steam and, it is on record, that in this small tunnel of 17 in. square section a wind speed of 60 ft. per second was obtained (that is, about 41 m.p.h.).

From then until 1903, the year of the first flight—less than a dozen experimental apparatus of this kind seem to have been constructed. One of these was made by Sir Hiram Maxim, who, however, with Langley, again made use of the whirling arm method of aerodynamic research.

Used by the Wrights

However, it is apparent that the results obtained by the Wright Brothers on a tunnel built by them in 1901 had a great bearing on the details of the design of their third glider, which was the precursor of their final power-driven aeroplane. The following is an extract from a lecture given in 1916 by Griffith Brewer before the Royal Aeronautical Society :

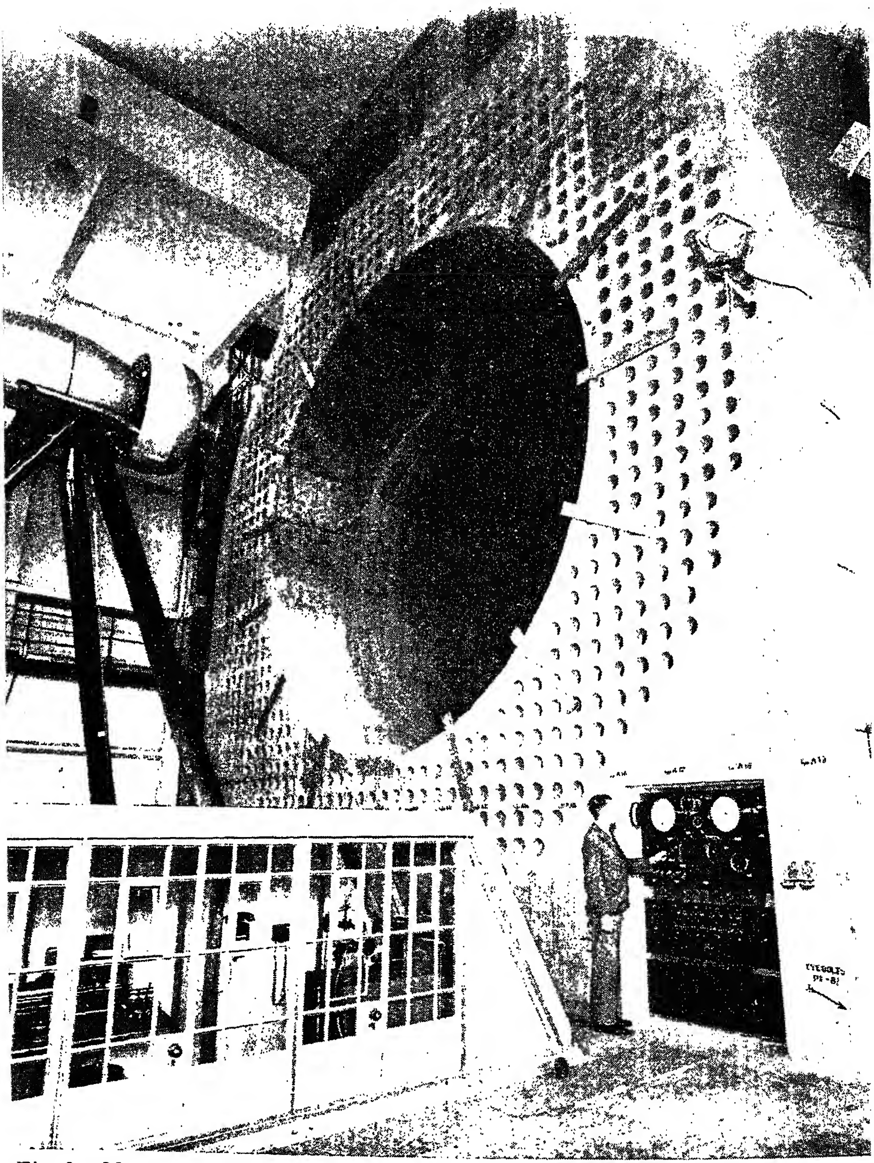
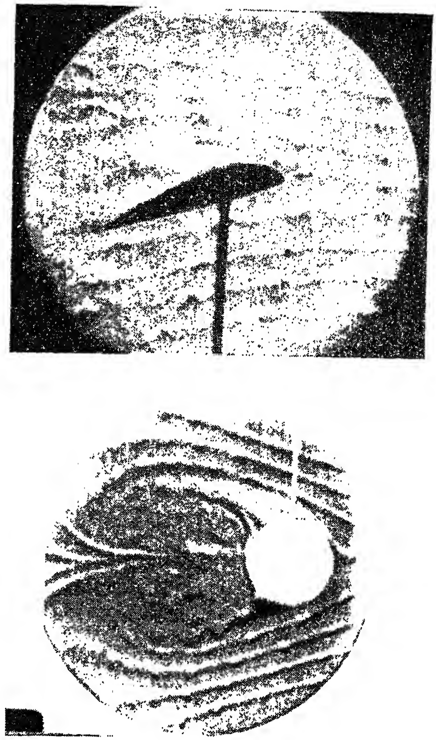


Fig. 2.—MAIN BALANCE HOUSE OF FULL SCALE WIND-TUNNEL AT R.A.E., FARNBOROUGH.

"On returning to Dayton in August, 1901, the Wrights decided to check the data given by Lilienthal by making independent experiments of their own, and they soon found many discrepancies which filled them

with interest and led them on to make experiments more thorough and complete than any scientific experiments on the subject hitherto made. They constructed a wind-tunnel 16 in. square inside measurement and about 6 ft. long, into one end of which a current of air was blown by a fan, and the direction of the draught was straightened by a series of 'pigeon-holes'," etc., and again, "The result of these experiments was the abandonment of the tables of earlier experiments which the Wrights had previously used, and the third machine built for the purpose of the continuation of the experiments at Kitty Hawk proved by the efficiency of its gliding angle that they were fully justified in going to the labour and expense of this independent scientific work."



Figs. 3*a* and 3*b*.—SHOWING AIRFLOW MADE VISIBLE BY THE METHOD DEVELOPED BY DR. TOWNEND OF THE NATIONAL PHYSICAL LABORATORY. (See also the articles on "Principles of Flight" in this volume.)

Description of a Wind-tunnel

A wind-tunnel usually consists of a tube of rectangular cross section, along which air is drawn by a fan. The air is never blown through the tunnel, since it has been found that greater steadiness of flow is achieved by suction. The fan varies in design with the particular requirements but is essentially similar to the airscrew used on an aeroplane. The air is always sucked through a baffle made in the form of a honeycomb, which has the effect of straightening the flow and preventing swirl. Wind-tunnels are of two main types, the open jet and the continuous. In the former, the working part is in a gap across which the air is drawn whereas in the latter it is enclosed and the model is generally observable through glass. The method of supporting the model varies—it can be either from above or below—but strength of the supports combined with smallness is the chief consideration, since the disturbance caused by even thin wires can be considerable. The speed of the airflow is generally measured by pitot tubes set in different positions inside the tunnel, and the most convenient speeds for working vary between about 40 and 60 m.p.h.

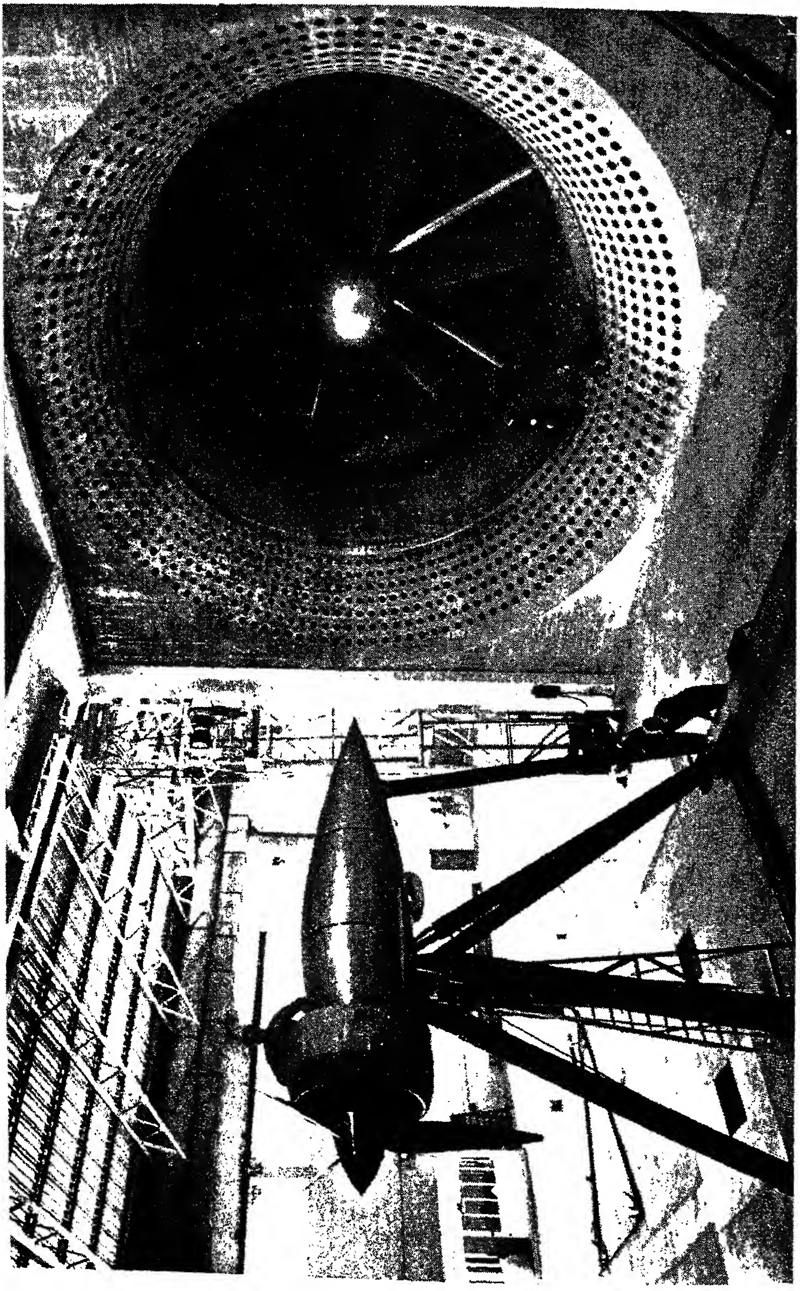


Fig. 4.—SHOWING COLLECTOR RING AND FAN WITH ENGINE NACELLE IN POSITION.

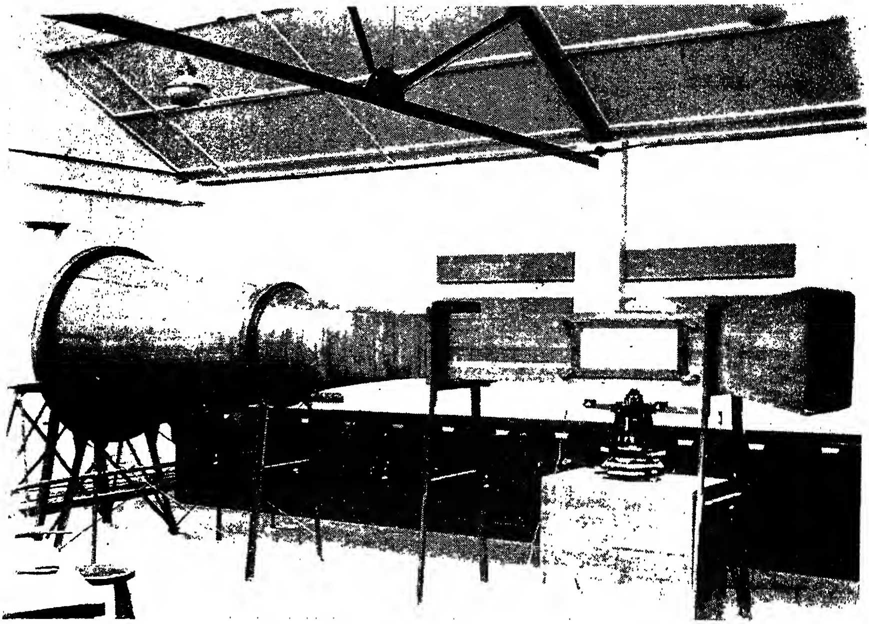


Fig. 5.—SMALL WIND-TUNNEL.

How Measurements are Made

In this article it is not possible to deal in detail with the more highly technical aspect of the subject, but a brief explanation is necessary of how the forces on a model are measured. Two wires, at "A," from the roof of the tunnel, support the main planes of the model, and another, at "B," the tail. These wires run through slots in the roof and are attached to balances set on a frame outside the tunnel. The drag is obtained by a third balance, but instead of a wire a rod is used at "C." The model is upside down in order that the lift may be in the same direction as the weight and the amount of lift is therefore the additional downward pull over and above the original pull before the airstream was introduced. If an inverted model were not used there would be danger of damage to the model as well as the apparatus due to the slackening of the tension in the supporting wires.

Now an aeroplane has three degrees of rotation—vertical, transverse and longitudinal—and study of its behaviour must be based on knowledge of the forces which set up couples about these three axes. Measurements of lift and drag are obtained and the pitching, rolling and yawing moments can also be measured. It is thus possible, for instance, to determine the correct tailplane angles for the model under investigation.

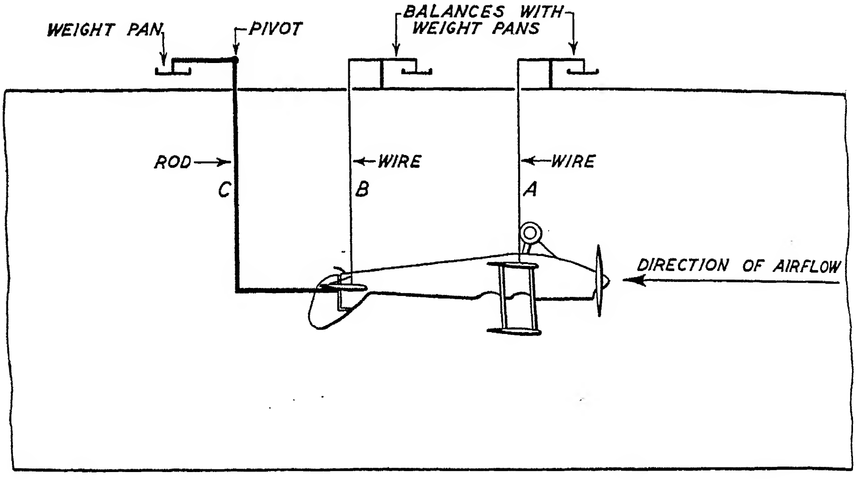


Fig. 6.—Showing diagrammatically how the forces are measured.

Similarly, data can be obtained for lift and drag for varying angles of incidence or for aerofoils of different sections.

As regards the difference between model and full-scale experiments, it will be sufficient to say that experience has shown that generally there is a very close agreement in the results.

Rayleigh's Law

The law relative to the prediction of full-scale results from data obtained from models was formulated by the late Lord Rayleigh. It is as follows: "If the flows past two geometrically similar bodies are similar, the forces or pressures on them are proportional to the square of the wind speed and to the linear dimension which defines their size."

This means that if in an ordinary wind-tunnel the model is one of a quarter full size and the speed of the airflow is also one-quarter—the forces acting on the full-sized aeroplane in actual flight will be found by multiplying the results obtained in the experiment by the square of 4 and again by the square of 4, *i.e.*, by 256. Any slight errors that may arise in the application of this rule will be due to "scale effect."

Scale Effect

Scale effects are caused by lack of similarity between the airflow over the relatively small model in the relatively low windspeed in the wind-tunnel and the airflow over the full-sized aeroplane at the relatively high speeds of flight. The airflow is dependent upon the size of model, the velocity of the wind and the density of the air, and similarity of flow over the model to that of full-scale flight can be obtained by increasing the density of the air in the wind-tunnel sufficiently.

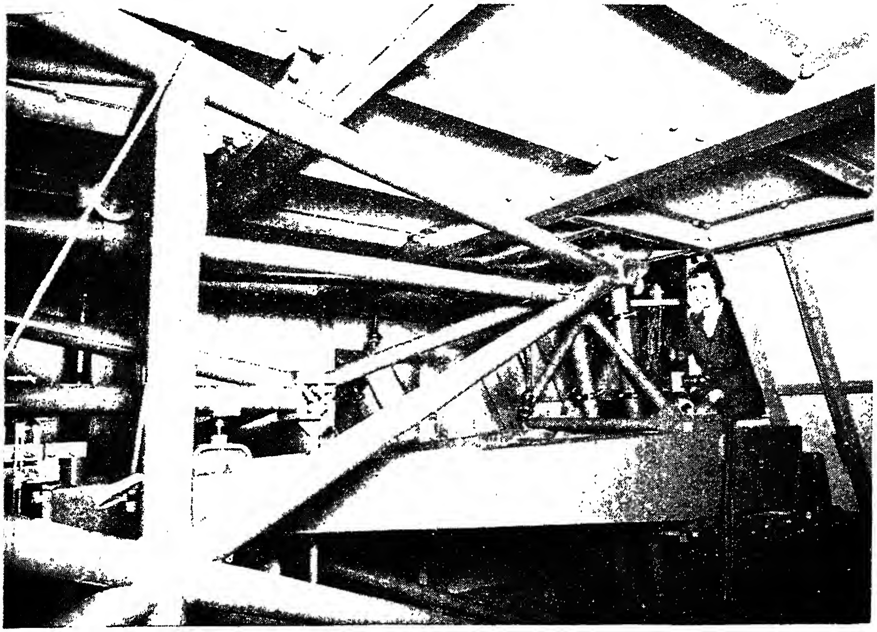


Fig. —ADJUSTING THE BALANCE PRIOR TO MEASURING FORCES ON THE FULL SCALE WIND-TUNNEL AT R.A.E., FARNBOROUGH.

The Compressed Air Tunnel

To this end a compressed air tunnel has recently been constructed at the National Physical Laboratory at Teddington, in which work can be carried out in pressures of up to more than twenty atmospheres.

Experiments with Full-sized Aeroplanes

The difficulties of studying accurately the effects of different types of engines mounted in airframes have prompted scientists to construct tunnels of the open jet kind large enough to take full-sized aeroplanes. The first wind-tunnel of this kind was built in America but recently one has been installed at the Royal Aircraft Establishment at Farnborough. In this tunnel much valuable data has been obtained, particularly in connection with engine cowlings and airscrews.

The Vertical Tunnel

One of the most difficult of the many problems that have faced the scientist has been the spinning of aeroplanes. To spin is often useful and it has for long been a manœuvre that every pilot has learned, if only to acquire the knowledge of the means of recovery—for many lives have been lost owing to an involuntary spin at a low altitude or to spinning being a peculiarly stable state for certain types of aeroplane.

Fig. 8.—TAKING A READING OF A FORCE.

Recently there has also been built at Farnborough a vertical wind-tunnel in which a model is placed on an arm and swung out into the centre. When the airflow is started—in an upward direction—the model is lifted from the arm and, if the control surfaces have been set in the proper positions, will spin continuously. By means of slow motion photography its behaviour can be carefully observed. The data obtained in this wind-tunnel has been of very great value in solving this particular problem.

To Study Airflow

No description of wind-tunnels would be complete without mention of the type developed by Mr. W. S. Farren, the present Deputy Director of Scientific Research of the Air Ministry. By means of a tunnel of very small section, combined with a system of magic lantern, coloured smoke and a multiplicity of small models, he has made possible the projection on to a screen of the picture of the behaviour of airflow under varying and almost endless conditions.

Another method of making airflow visible in a wind-tunnel has been developed by Dr. Townend of the National Physical Laboratory, consisting of the adaptation of what is known as the "Schlerin effect," whereby heated air is made visible by means of an optical device. Figs. 3*a* and 3*b* are examples of this.

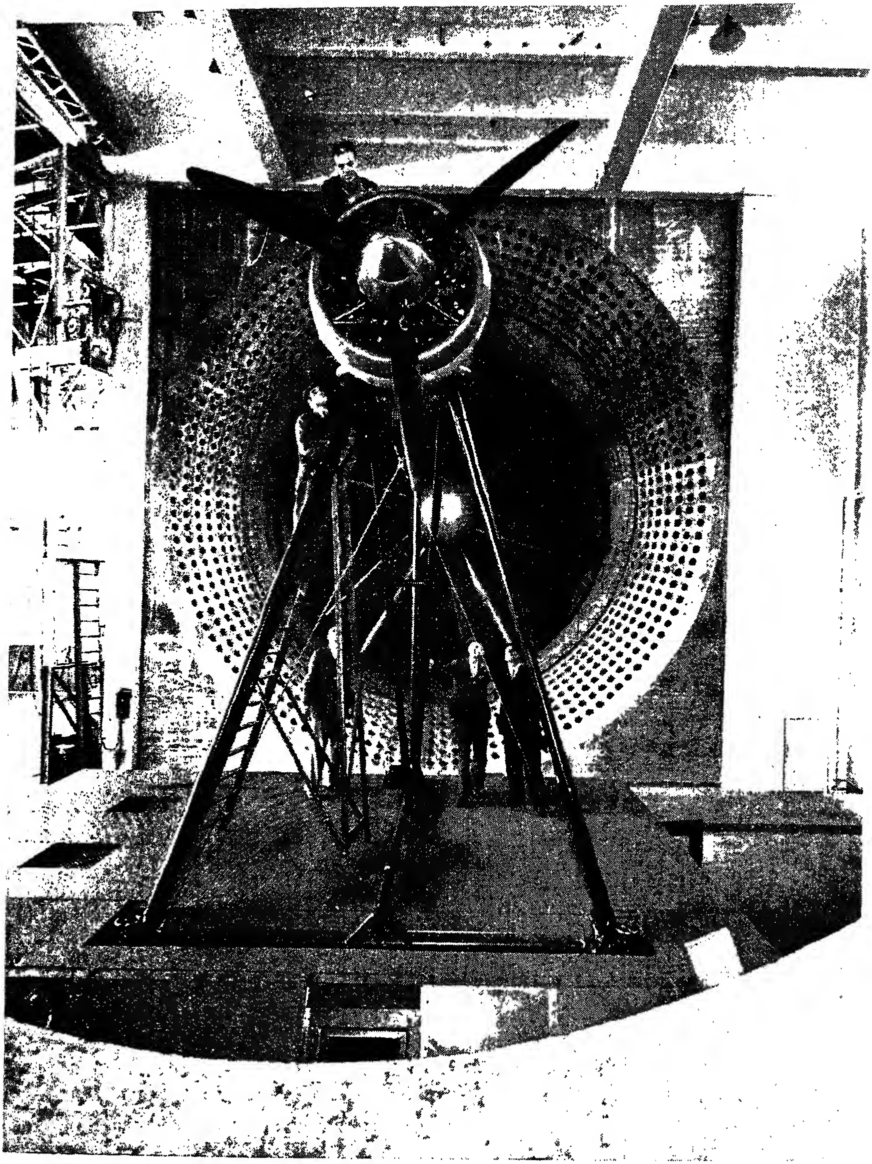


Fig. 9*a*.—ERECTING AN ENGINE NACELLE WITH TOWNEND RING FOR TEST IN THE FULL SCALE WIND-TUNNEL AT R.A.E., FARNBOROUGH.

Water Tanks

Some of the early types of aeroplane were made to take off from and alight on water. This necessitated a different kind of undercarriage on

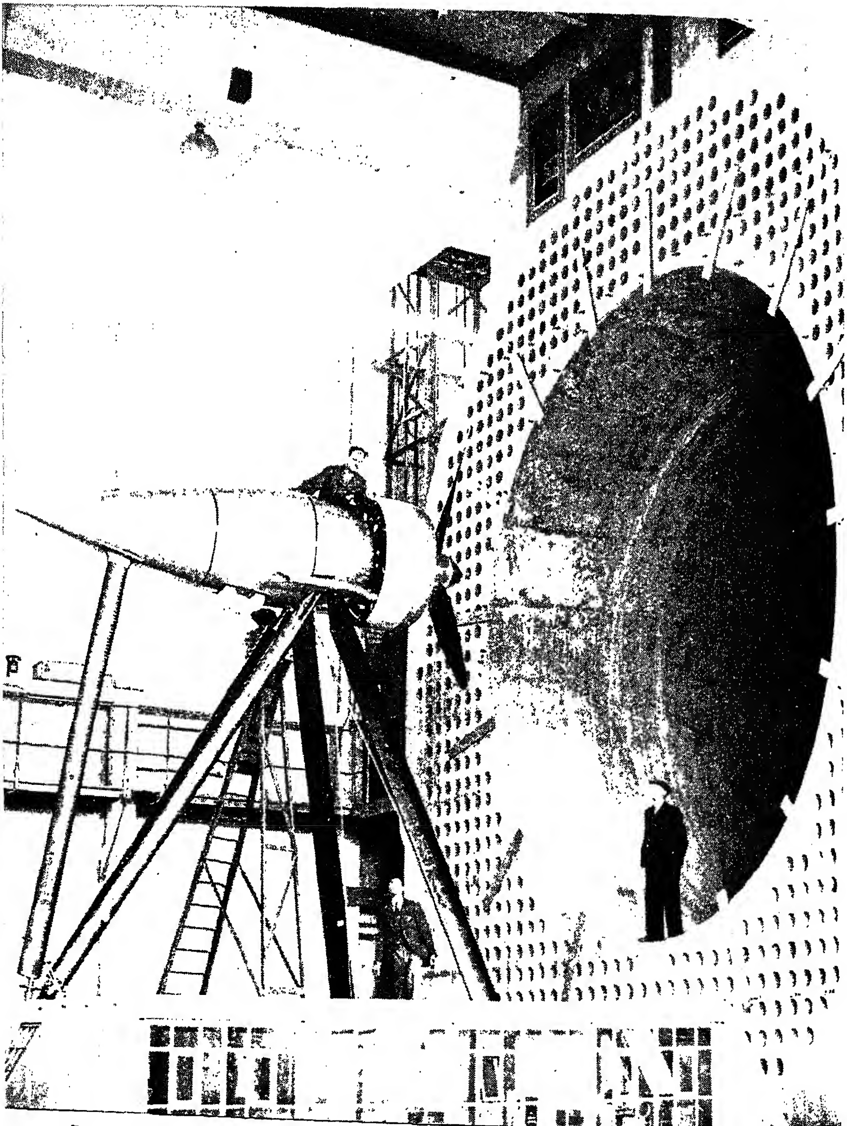


Fig. 9b.—ERECTING AN ENGINE NACELLE WITH TOWNEND RING FOR TEST.

which floats took the place of wheels. The float plane has now given way to the flying boat and much work has been necessary in the investigation of the behaviour of these craft. So far as the study of the problem of design of float or hull is concerned, work on models is done by towing

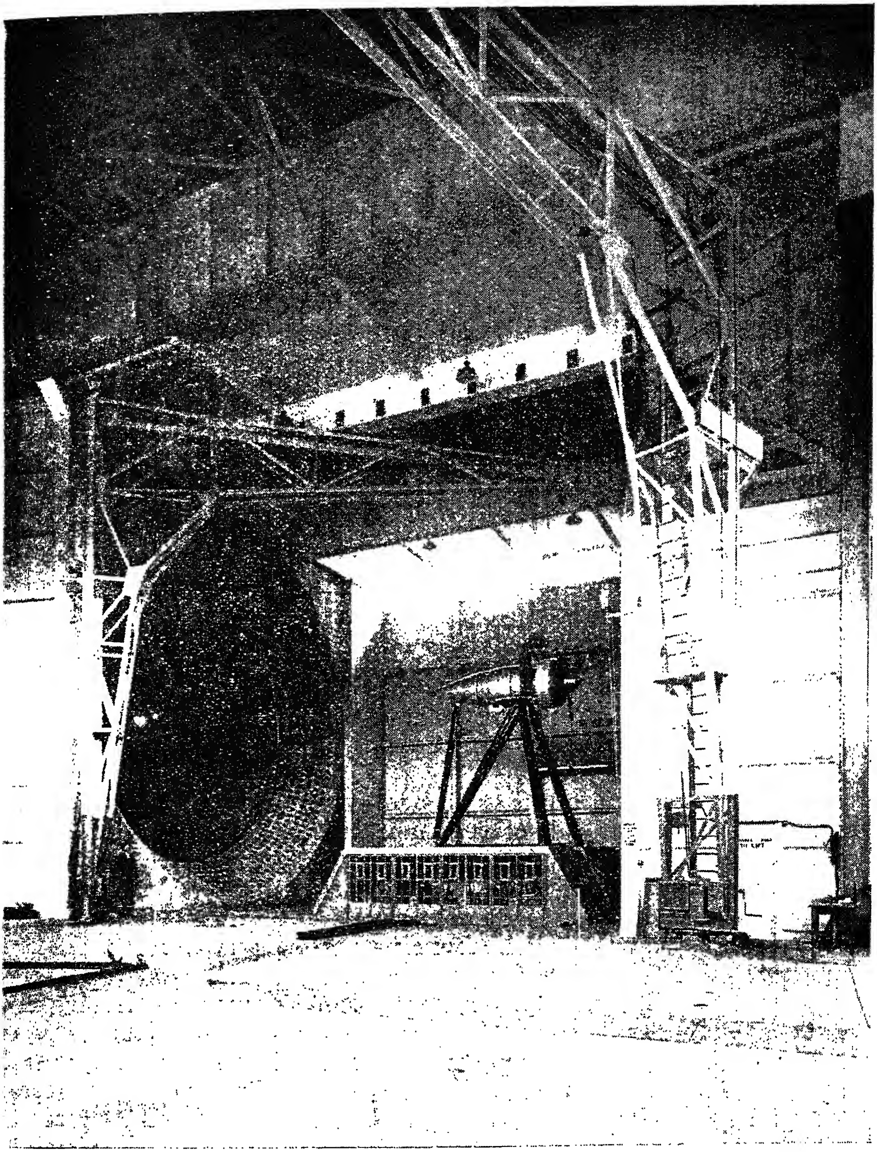


Fig. 9c.—Erecting an engine nacelle with Townend ring for test.

scale models in a tank and measuring the reactions set up by the motion through the water.

Many firms have water tanks for research of this kind; the National Physical Laboratory, however, is probably better equipped in this respect

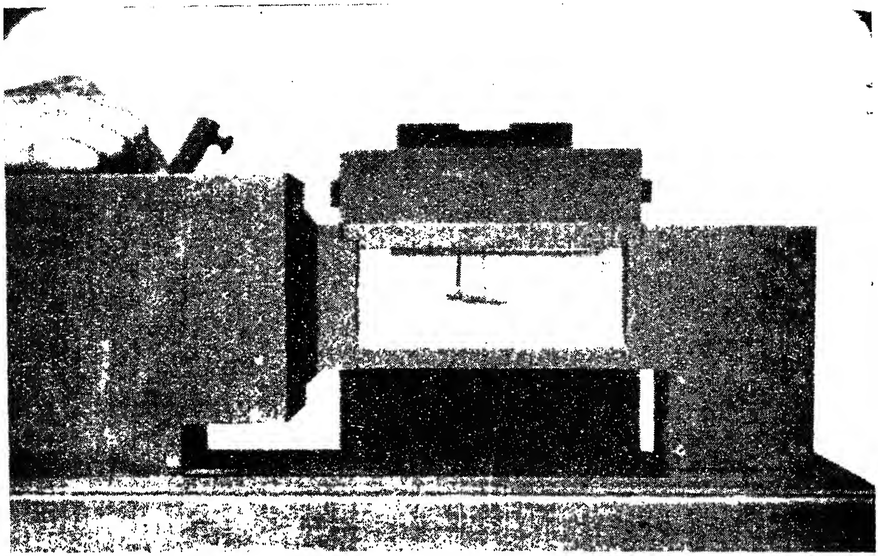


Fig. 10.—AN EARLY METHOD OF SHOWING AIR FLOW.
Using a smoke tunnel with model suspended in stream.

than any other laboratory in the world. The tank there is 550 ft. long, 30 ft. wide and 13 ft. deep, and models of ships of all kinds, from racing craft to the biggest liners and battleships, as well as the hulls and floats of aircraft, are tested there.

Anyone interested in this subject might try the simple experiment of moving a flat plate or body of any shape desired slowly in a tank or bath, on the water of which aluminium powder has been recently sprinkled. Flow patterns will be easily seen very similar to those produced by smoke in a wind-tunnel and the study of the vortices set up by the least movement through the water will be found interesting and fascinating.

Flow similar to that obtaining in normal flight can be achieved in water with small models and relatively low velocities owing to the fact that the density of water is much greater than that of air. In the case of water, however, or of any other fluid, the kinematic viscosity enters into scale effect—but that is a matter too complicated to deal with here. It may perhaps be of interest to give Froud's Law of Corresponding Speeds by which the conversion to full scale of results obtained on a model may be computed. By this law the scale model must be towed through the water at a speed equal to the full-scale speed multiplied by the square root of the scale. Thus, if the taking-off speed is 60 m.p.h. and the model is made to one twenty-fifth scale, it should be moved through the water at $60 \times \sqrt{\frac{1}{25}}$, that is, at 12 m.p.h. Similarly, a one-sixteenth scale model for the same taking-off speed should be towed at 15 m.p.h.

REID-SIGRIST TURN INDICATOR

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.(Retd.)

Purpose of the Turn Indicator

In the early stages of flying, pilots were very careful to steer clear of clouds, navigation in which always presented difficulties on account of the lack of adequate instrument equipment. In those days, night flying was unusual, and in any case a dangerous pursuit; while attempts at cloud flying (other than a climb or dive through clouds of perhaps only 1,000 ft. thickness) were frequently attended by crash or fatality.

The usual sequence of events when entering a cloud or flying in very thick weather was somewhat as follows :—

(1) At the outset the pilot would endeavour to keep a straight course by intense concentration on his compass needle, and would make slight adjustments to the rudder at the first sign of any deviation from his set course. At the same time it was necessary for him to watch the revolution indicator or air speed indicator, to see that the nose of the aeroplane was not falling.

(2) Slight inattention or lack of concentration might result in a somewhat increased deviation of the aeroplane from the set course; and on account of the lag of the compass this was indicated a second or two later than the deviation actually began. The pilot attempted to correct this deviation, but although the aeroplane responded instantly, there was still greater delay before the compass showed the effect of his correction.

(3) The certain result of this compass lag was over-correction by the pilot, so that the aeroplane turned from one side to the other in increasing arcs, the compass swinging more and more widely until it would only spin round; and at that time there was a belief that this spinning of the compass was due to some electrical effect of clouds.

Fatalities and crashes due to this cause ended with the introduction of gyroscopic methods of blind flying, the first and most useful instrument being the turn indicator.

The turn indicator is only one of several types of gyroscopic instruments which will indicate accurately and immediately changes in the attitude of the aeroplane. The gyroscopic equipment of modern military, as well as a high proportion of civil aeroplanes, is as follows :—

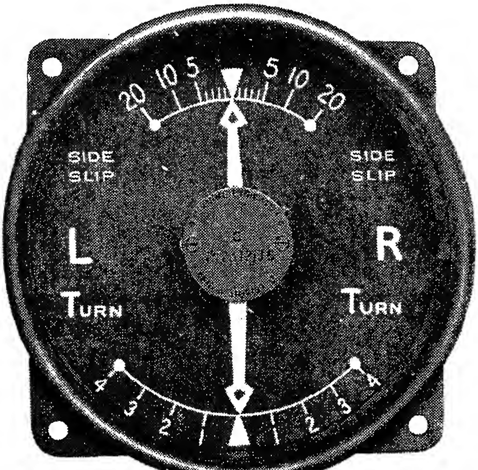


Fig. 1.—DIAL OF REID TWO-NEEDLE TURN INDICATOR.

(1) A gyroscopic artificial horizon, which indicates any deviation from normal flying level and flying straight attitudes; that is it gives indications of the extent of pitch or bank.

(2) A direction indicator or gyro compass which will indicate deviation in degrees from a set course. Like the artificial horizon, it has a free gyro; and it indicates the amount (that is the number of degrees) of a turn.

(3) A turn indicator, in which the gyro is confined to a limited movement by means of a spring; the more rapid the turn, the wider the movement of the gyro and the indicating needle within the limits set. The indication is the rate of turn—the number of degrees per minute.

Deviation from normal attitudes is indicated in three dimensions by the artificial horizon and directional gyro; but in common with any free gyro instrument produced up to the present and suitable for continuous use, there is a limit to the attitudes in which these instruments will function. Some of them will continue to give reliable indications during a loop, but none of them will also function continuously during a spin. Depending on the type of instrument and method of mounting, acute attitudes usually result in free gyro instruments going out of action; but the constrained gyro of the turn indicator will continue to function in all attitudes of flight.

A turn indicator is therefore fitted to all military and other aeroplanes in which aerobatics might be necessary, even though artificial horizon and directional gyro also form part of the equipment. The greatest use of the turn indicator is during a spin or during the recovery period following upon it; a manœuvre in which other free gyro instruments cease to function.

In the Royal Air Force, spinning is taught by means of the turn indicator; all Royal Air Force aeroplanes throughout the world are fitted with a turn indicator made by Reid & Sigrist Ltd.

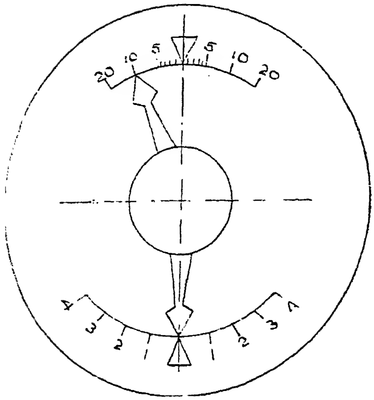


Fig. 2.—POSITION OF NEEDLES WITH BANK AND NO TURN.

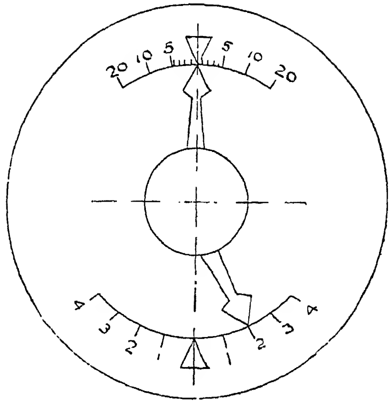


Fig. 3.—CORRECT BANK AND TURN.

Indications Given by the Reid Two-needle Turn Indicator

The type of turn indicator most commonly in use is the standard pattern as supplied to the Air Ministry, of which many thousands have been made. This is the Reid Two-needle Turn Indicator.

Dealing first with the exterior appearance of the instrument, the dial is shown at Fig. 1, the lower needle being that connected to the gyro, and indicating turn. The arc at the bottom of the scale is graduated from 1 to 4 in either direction, these figures indicating various rates of turn.

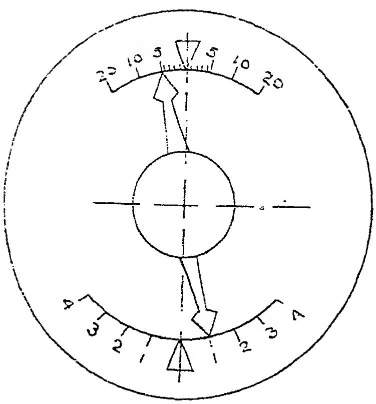


Fig. 4.—CORRECT BUT WITH A LITTLE OUTSIDE SLIP.

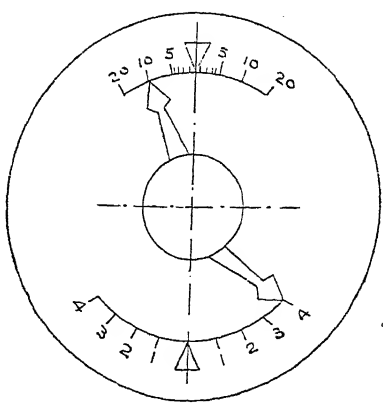


Fig. 5.—WHEN SPINNING TO THE RIGHT.

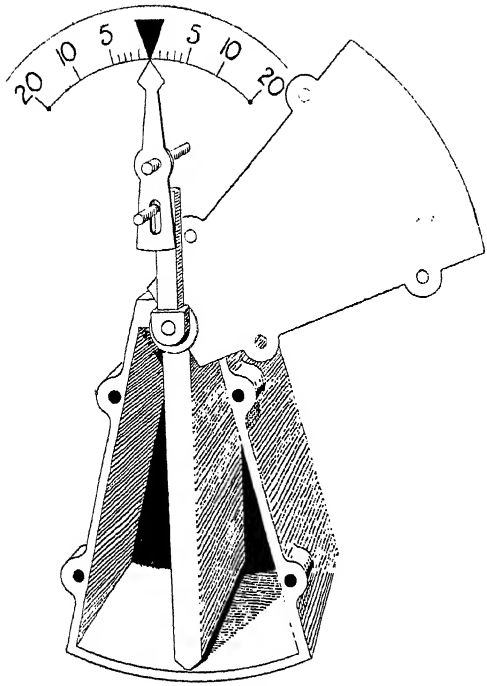


Fig. 6.—THE INCLINOMETER UNIT.

The time for a complete turn at each of these indications is as follows:—

Rate of turn on dial.	Time for complete turn of 360°.
1	2 mins.
2	1 min.
3	32 secs.
4	20 ,,

These figures apply to the instrument as at present being made for the Royal Air Force; recently slight changes have been made in the design and the Air Ministry have asked for standardised rates of turn as detailed above; but many thousands of turn indicators are in use in which the rate of turn has been adjusted to the previous Air Ministry standard; the figures were then as follows:—

Rate of turn on dial.	Old instrument.
1 .	3 mins. 40 secs.
2 .	1 min. 56 ,,
3 .	1 ,, 12 ,,
4	40 ,,

All the older instruments can be identified by the inscription on the small dial in the centre; old type instruments are styled Mark 1, and new type instruments Mark 1A. Fig. 1 clearly shows a Mark 1 instrument.

The most important indication of this instrument is that given by the turn indicator needle, showing instantly deviation from straight flight; the top needle indicates in degrees the amount of bank; and when making turns at various banks, the two needles should be read in conjunction.

Fig. 1 shows the appearance of the needles in straight flight, with no bank; Fig. 2 shows a bank without turn, in which the aeroplane will be side slipping to the left.

The side slip and bank indication is dependent upon a pendulum and is non-gyroscopic. A pendulum is affected by gravitational and accelerational forces; and tends to hang vertically in relation to the

earth when the aeroplane has banked, but is not turning. A correct indication of the number of degrees of bank is then given by the top needle.

But when the aeroplane is turning, the pendulum will be affected also by the centrifugal force due to the turn; and this will tend to swing the pendulum outwards and upwards. The perfect turn results when this effect on the pendulum is exactly balanced by the downward effect of gravity; and however steep the bank, if the rate of turn is correctly adjusted to it, the top needle will remain at zero as shown in Fig. 3.

In blind flying it is usual to adhere to a slow rate of turn, such as rate 1; and under the technique at present used a little outside slip is permitted in order to prevent the nose of the aeroplane from falling. This is shown in Fig. 4; while a spin to the right is indicated in Fig. 5.

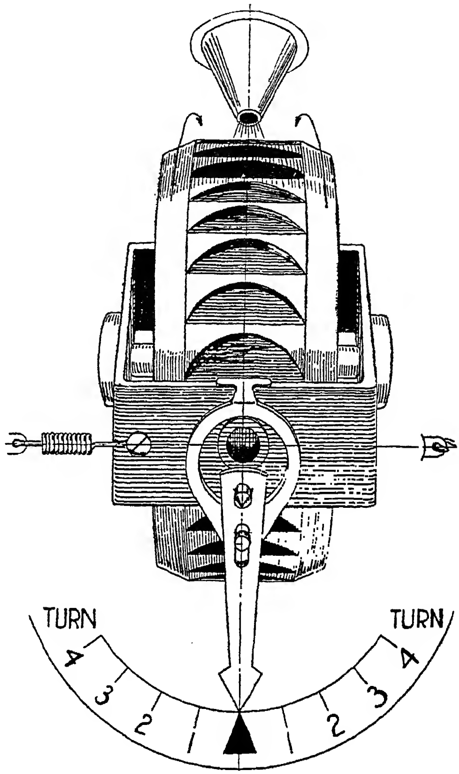


Fig. 7.—THE GYRO UNIT.

Construction of Reid Two-needle Turn Indicator

Dealing first with the construction of the simpler unit of the turn and bank indicator, Fig. 6 shows the pendulum, styled inclinometer unit. A pendulum in the open would rattle about with every bump or slight change in attitude of the aeroplane; it is therefore enclosed in an air-tight box with a very close-fitting lid and base; movement of the pendulum is impossible without a transference of air through that very small space from one side of the pendulum to the other, and this retards its movement sufficiently to provide damping of a high degree of efficiency.

The gyro unit is illustrated in Fig. 7. At the top of the illustration is a diagrammatic representation of the air jet, which blowing against the buckets cut in the rim of the wheel, drives the gyro at about 6,000 r.p.m. It will be seen that the gyro is mounted in a gimbal pivoted at each end, and is therefore free to precess clockwise or anti-clockwise according to a turn of the aeroplane either to left or to right.

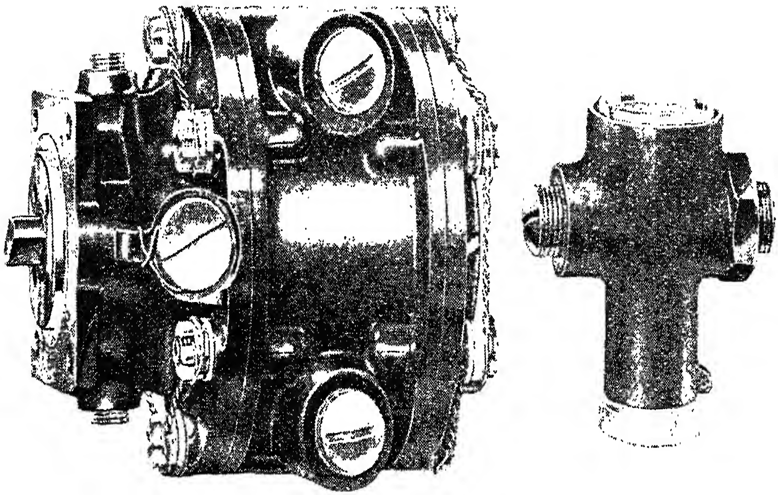


Fig 8.—ENGINE-DRIVEN SUCTION PUMP.

Air Supply

The instrument is enclosed in an air-tight case from which in flight the air is continuously exhausted by means of a venturi, the suction pump or the induction of the engine. The jet shown in Fig. 7 is the only inlet to the case, and the air rushing in through that jet in order to replace that exhausted by the means stated above, drives the wheel. The air suction required is equivalent to a depression of 3 in. of mercury at the instrument and the quantity is 0·25 cu. ft. of free air per minute.

Of the methods of air supply in use at present, the venturi tube is by far the most common; though with the increasing speeds of aeroplanes it will in time be replaced by engine-driven suction pumps. This pump is illustrated in Fig. 8.

The venturi is fitted with the small end forwards; the air flows in at the small end and out at the large end; it must not be interrupted by struts or other obstructions in front of or behind the venturi. It should point directly into the air-stream.

The testing, fitting and maintenance of this type of instrument is dealt with in a separate article.

THE REID AND SIGRIST GYORIZON

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

THE Turn Indicator used by the Royal Air Force as a standard is the Reid and Sigrist two-needle pattern, of which many thousands have been supplied to the Service during the last seven years; and this type is in use on every Royal Air Force aeroplane in the world to-day, being considered a necessity even when Artificial Horizon and Directional Gyro are also carried as part of the blind flying equipment.

On the Continent and in the United States of America a single-needle type of Turn Indicator is used; the needle (this time at the top of the scale) gives the turn, whilst the bank or sideslip component is indicated by a ball in a glass tube.

Although neither the two-needle pattern nor the single-needle type give to the pilot an exact picture of what is happening, the Air Ministry decided to retain the Reid two-needle Turn Indicator in use, partly because thousands of pilots had already been trained on this type, and partly because large numbers of the two-needle Turn Indicator are in use in the Service, so that conversion or replacement by a new pattern might be a very expensive business.

Why the Gyorizon was Introduced

For the use, however, of pilots in other countries, or civilian pilots in this country having no experience of the two-needle Turn Indicator, it was thought that a simpler form of dial might result in a clearer indication of what is happening to the aeroplane; and in an attempt to simplify blind flying training, the Gyorizon was produced as an addition to the other types of Turn Indicator on the market.

In designing this new instrument, other considerations were borne in mind. For lightness in weight and ease of production, the case of the instrument is a moulding. Care has been taken to guard against corrosion, by anodising, cadmium plating, and the use of stainless steel. Although instruments as at present produced are not fully tooled for mass production, it is possible to provide tools for most of the other main components which would enable very large numbers of these instruments to be produced with the minimum of labour.

Description of the Gyorizon

The most important part of the instrument is the dial, an illustration of which appears in Fig. 1. The needle, which indicates the rate of turn

By courtesy of "Flight."

Fig. 1.—REID GYORIZON.
Correctly banked turn.

of the aeroplane, is in the form of a model aeroplane with an extended nose indicating at the top of the dial the standardised rates of turn 1 to 4. In its normal position, that is for straight flying, the extended needle nose of the aeroplane points to the exact centre of the top scale, nose and fuselage lying along a line dividing the dial vertically into two exact semicircles.

The Bank Indication

The bank indication in this instrument is given by a liquid level; a suitable non-freezing liquid is enclosed in a very thin capsule mounted as a backing to the Turn Indicator needle, giving the effect of a liquid horizon. The capsule is so thin as to provide a pronounced damping effect upon the movement of the liquid, which instantly takes up, and retains without swinging, a position corresponding to the movement of the aeroplane. Since this liquid horizon is subject to forces of gravity and acceleration, it does not follow that it will indicate at all times an angle of bank; this point has been dealt with in a later paragraph.

The needle itself is luminised for convenience in night flying, and the scale is provided with luminised dots and a centre point, together with two luminised marks at the points where the tips of the wings will rest when the real aeroplane is in straight flight.

The Turn Indicator

The needle is connected to the Turn Indicator gyroscope, the construction of which will be clear from the illustration in Fig. 2. The wheel is provided with a series of milled buckets, on which the air impinges from a jet not shown in the illustration. The jet itself is attached to the casing of the instrument; from that casing the air is continuously withdrawn, either by a venturi tube or a suction pump; and the constant replacement of the partial vacuum thus set up—a suction head of approximately 3 in. of mercury—is continuously supplied by the inflow through the jet in the case. It is necessary of course for the case to be airtight other than the point of entry at the jet.

In Fig. 2 can also be seen the bearings in which the wheel revolves, and at the near end one of the pivots for the rocking movement of the

gimbal. As in all constrained gyros, the movement of the gimbal is restrained and the gimbal itself restored to normal position by a small spring shown below the near pivot; the tension on that spring adjusts the sensitivity of the instrument. It will perhaps be clear that the stiffer the spring the greater will be the force necessary to give any particular rate of turn in either direction.

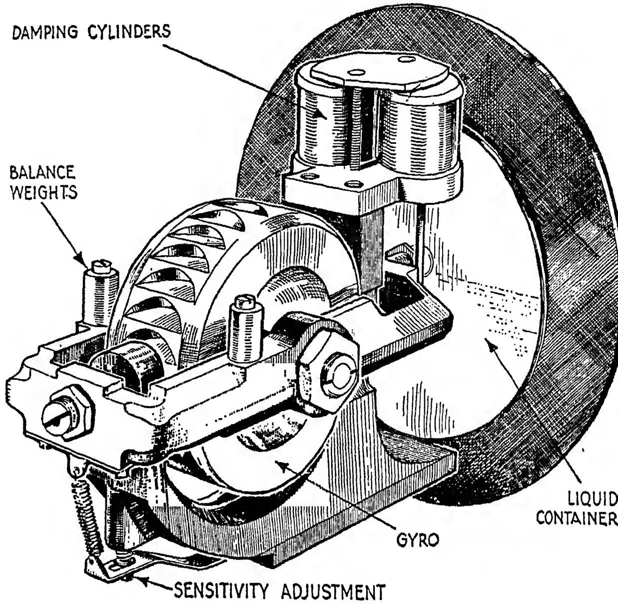


Fig. 2.—THE GYRO WHEEL, GIMBAL AND DAMPING DEVICE.

Damping Mechanism

The damping mechanism of the gyroscope consists of closely fitted pistons in blind cylinders. The damping effect is brought about by the slow transference of air from one side of the piston to the other. The pistons themselves are extremely thin, so that there is practically no friction against the cylinder wall, and this results in a form of damping in which the piston is absolutely free from any possibility of sticking at any point. The alternative to this method is a piston which depends upon friction instead of upon airflow, and, while such a method costs considerably less, there is always the possibility of the friction resulting in a sticking of the needle.

Indications given by the Reid Gyorizon

Dealing first with the indication of turn alone, the scale at the top of the dial indicates varying rates of turn, the time for a complete turn being set somewhere between a minimum and maximum amount. That is, the average of all instruments turned out will lie between the figures shown in the following table :—

Rate of turn on dial.	Time for complete turn of 360°. Minimum.	Maximum.
1	2 mins. 48 secs.	3 mins.
2	52 ,,	1 min. 4 secs.
3	24 ,,	36 ,,
4	14 ,,	24 ,,

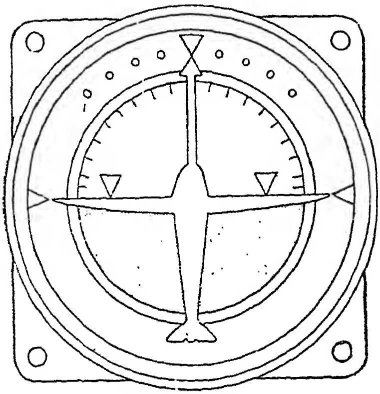


Fig. 3.—No bank or turn.

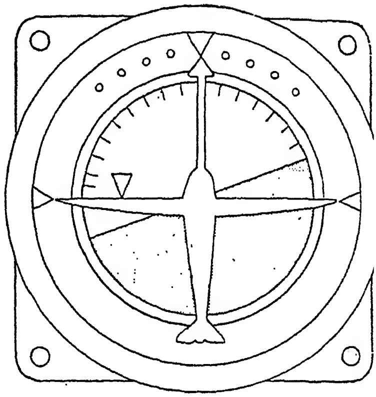


Fig. 4.—Sideslipping to the right without turn.

It is of course intended that the Turn Indicator needle in the shape of an aeroplane should be read in conjunction with the indication given by the liquid horizon, and the simplest method of appreciating the indications of this instrument would perhaps be to consider first the behaviour of the liquid horizon alone.

Banking without Turn

Unless it is acted upon by other forces, the liquid will of course tend to flow downhill when the instrument (or the aeroplane to which it is attached) is tilted, as when banked one way or the other, but without turn. This indication is shown in Fig. 4. It will be seen that the needle points to the centre of the turn scale, indicating that the real aeroplane is flying straight ahead; but the liquid horizon is tilted in regard to the case of the instrument—and also in regard to the horizontal wings of the little aeroplane—the angle between the horizontal wings and the liquid horizon indicating that, although flying straight, the aeroplane will be slipping downhill to the right, that is, to starboard.

Sideslipping without Turn

This is sideslipping without turn, one wing of the aeroplane being down *in relation to the liquid horizon*, although the wings are still horizontal in relation to the scale of the instrument. Fig. 4 may be compared with Fig. 3, which shows the indication when the aeroplane is flying straight and level, no bank or turn.

Correctly Banked Turn

No diagram has been provided for a correctly banked turn, as this is already illustrated in Fig. 1. Although the rate of turn needle shows that the aeroplane is turning rapidly at rate 3, the liquid horizon remains

perfectly horizontal in relation to the case of the instrument, despite the fact that to compensate for such a turn there will be a considerable angle of bank. Under these conditions the downward pull of gravity on the liquid is exactly balanced by the outward and upward pull of centrifugal force due to the turn, and the liquid horizon in this position indicates that the turn is correctly banked.

How Errors are Indicated

Supposing that the turn were not correctly banked, the horizon will give an instant indication of this error. Fig. 5 shows a flat turn to the left and the parallelism of the wings with the horizon, despite the turn indicated, will convey immediately to the pilot that a sideslip must be occurring outwards as in any other flat turn. This is an extreme case, the angle of bank being so slight that the liquid is flung outwards and upwards to a greater extent that it is pulled downwards by gravitational force; but any indication in which the liquid horizon falls below the triangular datum marks of the instrument at either side of the scale will indicate a turn without sufficient bank, and also a sideslip outwards—assuming of course that the turn needle is giving some indication other than zero.

The opposite indication is illustrated in Fig. 6, showing a rate two turn slightly overbanked, with the result that the liquid horizon runs downhill more than the centrifugal force pulls it uphill. Once again the appearance of the liquid, in relation to the pictured wings of the aeroplane, conveys to the mind of a pilot that for such a rate of turn he will be slipping downwards towards the horizon.

Turn Indicators, in which the gyro is constrained by a spring, are the only blind flying instruments which will remain in action during a spin, and the indication given is shown in Fig. 7, where the real aeroplane is

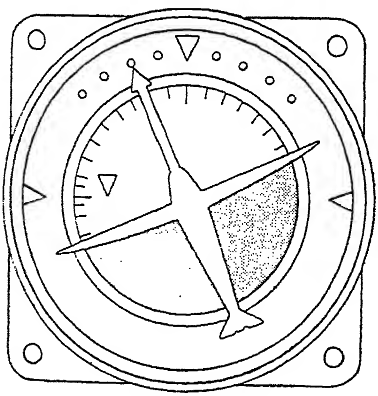


Fig. 5.—FLAT TURN TO LEFT.

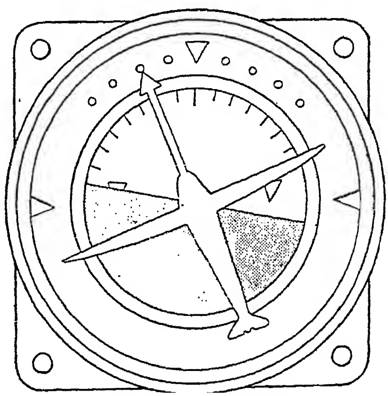


Fig. 6.—AN OVERBANKED TURN.

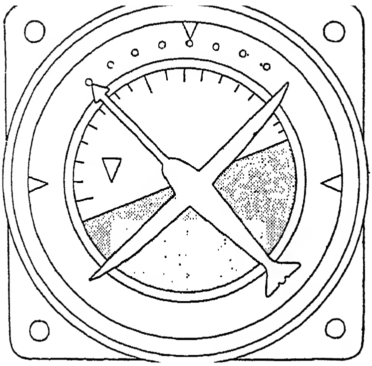


Fig. 7.—SPINNING TO LEFT.

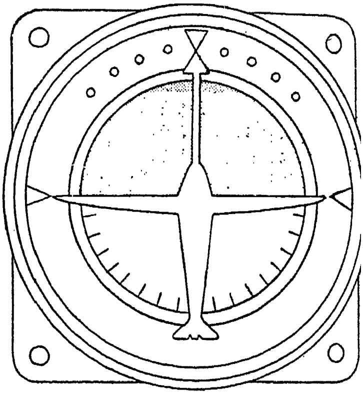


Fig. 8.—APPEARANCE OF DIAL IN INVERTED FLIGHT.

spinning to the left. The maximum possible rate of turn is shown, accompanied by considerable outside slip, despite the acute bank of the real aeroplane. Continuous functioning of a Turn Indicator in any attitude means that it will continue to give an indication of turn or bank even when inverted and the appearance of the dial in inverted flight is shown by Fig. 8.

Suction Drive for Gyorizon

Like any other air-driven instrument, the drive for the Gyorizon can be provided in the following ways :—

1. By means of a venturi tube, illustrated on p. 237 of this volume.
2. By suction from the induction pipe, a method much used in America and on the Continent. The leakage of air is almost infinitesimal and experiments show that there is no effect upon the slow running of the engine.
3. By means of a suction pump which might be driven by a windmill, a small independent electric motor or as at present planned by being coupled to suitable gearing on the main engine.

The single jet of the instrument takes 0·25 cu. ft. of air per minute, and the suction at the instrument should be equivalent to a depression of 3 in. of mercury, as stated previously. In first fitting an instrument to a new type of aeroplane, it is usual to measure its suction by a manometer when the aeroplane is in flight ; this procedure is dealt with in a later article.

Further Details of Gyorizon

Like the Reid and Sigrist two-needle Turn Indicator, the Gyorizon has the following advantages :—

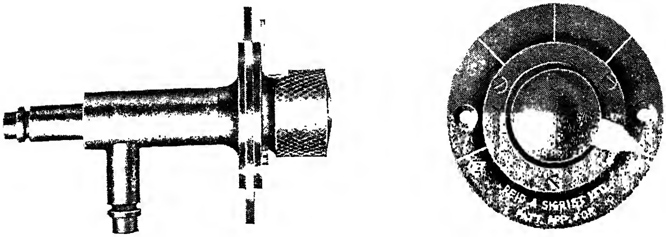


Fig. 9.—SENSITIVITY CONTROL.

1. It starts on $\frac{1}{4}$ in. of mercury pressure ; this means that it requires very little suction to start the gyro, which runs as soon as the engine of the aeroplane starts to tick over.
2. The wheel will continue to run for approximately eighteen minutes after suction has ceased.
3. The instrument functions at plus or minus 60° C.

It has the same movement as the instruments used for the flight over the summit of Mount Everest, which functioned perfectly during this severe test, where temperatures were as low as minus 55° C. at heights of over 29,000 ft.

The weight of the instrument is	1 lb. 4 oz.
Size of case being . . .	$3\frac{3}{4}$ in. diameter.
And the size of dial . . .	$3\frac{3}{8}$ in.

When in position on an aeroplane the case projects behind the dashboard for $3\frac{3}{4}$ in.

Sensitivity Control

Like the two-needle Turn Indicator, the Gyorizon leaves the maker's works adjusted to a standard sensitivity, and any variation which is to be carried out by means of a turn or two of the sensitivity spring will be dealt with in an article on fitting and maintenance of Turn Indicators. It is possible, however, that the preference of a pilot as regards sensitivity may vary from one day to another and reduced sensitivity might be required in a flight made in very bumpy weather. Similarly, the setting of the sensitivity spring is standard for any type of aeroplane when the instrument leaves the factory ; but if adjusted in a squadron or by a private owner it might not suit all the pilots who use that particular aeroplane ; while any instrument will be considerably more sensitive on a high-speed as compared with a low-speed aeroplane.

The firm of Reid and Sigrist have therefore produced a sensitivity control intended for operation by the pilot in the air or otherwise. It enables the suction from the venturi, and consequently the speed of the gyro, to be controlled from the dashboard, thus giving different sensiti-

vities to suit individual requirements and all types of aeroplanes in various circumstances.

The device is fixed to the dashboard near the instrument it is intended to control. The venturi is connected to the vertical tube of the sensitivity control by pitot tubing or rubber tubing, and the horizontal tube of the sensitivity control is also connected to the instrument outlet by a short piece of pressure pitot tubing or rubber tubing. If rubber tubing is used it should be wired to the connection. The sensitivity control is illustrated in Fig. 9.

It is equally applicable when the instrument has induction or pump drive.

QUESTIONS AND ANSWERS

What Form of Needle is Used with the Gyorizon?

The needle is in the form of a model aeroplane with an extended nose indicating at the top of the dial the standardised rates of turn 1 to 4.

What is the Position of the Needle During Straight Flying?

The extended needle nose of the aeroplane points to the exact centre of the top scale, nose and fuselage lying along a line dividing the dial vertically into two exact semicircles.

How is Bank Indication given by this Instrument?

By a liquid level; a suitable non-freezing liquid is enclosed in a very thin capsule mounted as a backing to the turn indicator needle, giving the effect of a liquid horizon. The capsule is so thin as to provide a pronounced damping effect upon the movement of the liquid which instantly takes up, and retains without swinging, a position corresponding to the movement of the aeroplane.

What Indication is given that an Aeroplane is Banking without Turn?

The needle points to the centre of the turn scale, indicating that the real aeroplane is flying straight ahead, but the liquid horizon is tilted in regard to case of the instrument, the angle between the horizontal wings and the liquid horizon indicating that, although flying straight, the aeroplane will be slipping downhill.

REID COMMERCIAL TYPE TURN INDICATOR

(BUBBLE MODEL)

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

SOME years ago a prolonged series of experiments was undertaken by the British Air Ministry with a view to determining the type of Turn Indicator most suitable to the needs of the Service, and especially to decide the preference of pilots for any particular type of dial.

An Interesting Series of Experiments

The research departments of the Air Ministry investigated by laboratory experiments the efficiency, reliability and life of the various Turn Indicators; and numbers of each type of instrument were sent out to Squadrons for report by pilots after lengthy flying trials, extending over a period of months.

The result of these experiments was a decided preference by British pilots for the two-needle type of Turn Indicator, *the bottom needle* indicating turn.

On all other types tried, the top needle shows turn, and instruments of this type are almost universally used throughout the Continent and United States of America. The construction of a Turn Indicator with the needle at the top is rather more simple than that of the Royal Air Force pattern and consequently it is a somewhat less expensive instrument.

To meet commercial requirements for this type of instrument in this country and abroad, the Reid and Sigrist commercial model Turn Indicator was produced.

Description of the Reid Commercial Turn Indicator

The dial of this instrument therefore corresponds closely to the Turn Indicators in use in the United States and over the greater part of the Continent. An illustration appears as Fig. 1. A heavily luminised needle moves over a scale at the top of the dial, subtending an angle of rather more than 90°; the various rates of turn are indicated by luminised spots, but are not numbered; and for use in this country the letters "L" and "R" indicate a turn to the left or right respectively. Dials made for abroad are lettered according to the language of the country concerned, and the words TURN and SIDESLIP must also be translated accordingly.

Bank or sideslip is indicated by a ball in a glass tube practically filled

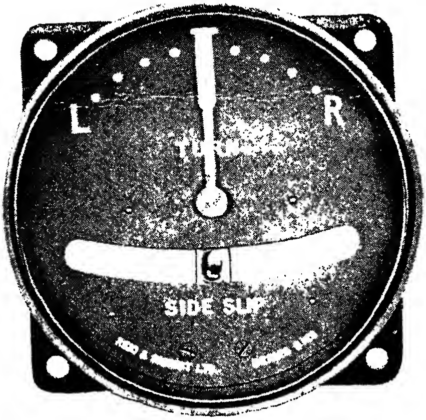


Fig. 1.—THE DIAL OF THE COMMERCIAL TYPE TURN INDICATOR (BUBBLE MODEL).

with liquid. The glass tube has been blown to the required shape and is therefore frequently styled a "bubble." It is essential that there should be no confusion between the glass bubble and the tiny bubble of air which appears in most of these glass tubes to allow for expansion of the liquid. No notice is taken by the pilot of this little bubble, which surrounds the ball when the latter is in the centre of the scale, but goes in the opposite direction for any other indication.

The steel ball, normally central in the tube, takes up various other positions dependent upon the bank of the aeroplane and the amount of centrifugal force due to a turn. Its movement in either direction is heavily damped by the non-freezing liquid, and it forms an inexpensive and simple indication of the accuracy of a particular turn.

Apart from the dial, the remaining part of the instrument corresponds very closely to the gyroscope assembly of the Gyorizon, dealt with in a previous article. It consists, as before, of an air-driven gyroscope mounted in a horizontal gimbal ring, whose pivots lie on a line normal to the plane of the dial; that is, these pivots are in the fore and aft axis of the aeroplane when the instrument is fitted in the usual position on the dashboard. The gyro, its gimbals and the controlling spring, and damping cylinders, are illustrated on p. 227 of this volume; the only difference between this mechanism and that of the Gyorizon being in the method of indicating bank and sideslip.

For standardisation purposes, a large proportion of the components in this instrument are exactly the same as those in the Gyorizon, almost the only difference being in the dial itself. The case is made of black bakelite to the same moulding as the Gyorizon and has the same suction nipple and air intake to the jet, complete with filter.

Every care has been taken to ensure that the mechanism is corrosion-proof; aluminium parts are anodised and sometimes painted as well; steel screws or other parts are cadmium or chromium plated; and stainless steel is used wherever possible. The case itself must be airtight when the air intake filter is closed; and although the filter itself is not entirely dustproof (as it would then not permit the passage of the air) there is constant suction when the instrument is working, which draws out of the case any fine dust which might pass the filter gauze.

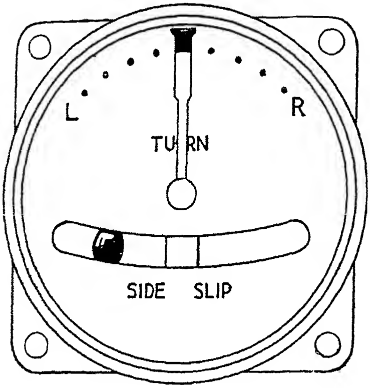


Fig. 2.—SIDESLIPPING WITHOUT TURN.

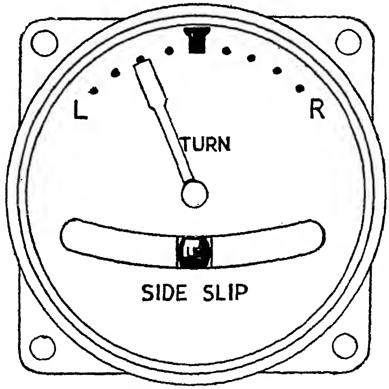


Fig. 3.—CORRECTLY BANKED TURN TO LEFT.

Indications given by the Reid Commercial Turn Indicator

As the gyro mechanism of this Turn Indicator is the same as the Gyorizon, the rates of turn at various readings on the scale will also be the same; and these are repeated below. The time for a complete turn is set between a minimum and maximum amount, the average of all instruments turned out lying between the figures quoted in the following table:

Rate of turn on dial.	Time for complete turn of 360°.	
	Minimum.	Maximum.
1	2 mins. 48 secs.	3 mins.
2	52 ,,	1 min. 4 secs.
3	24 ,,	36 ,,
4	14 ,,	24 ,,

The readings given by the Turn Indicator needle are exactly the same as those of the aeroplane shaped needle on the dial of the Gyorizon; dealing with the simplest case, straight and level flight is indicated by Fig. 1, the same illustration in which the dial of the instrument is shown. The ball is central between two marks etched on the glass bubble, and the turn needle indicates by its centrality no deviation from straight flight.

Bank alone can be indicated by the movement of the ball in the tube, and it will be obvious that when the aeroplane is tilted the ball will run along the tube to the downward end; and the commencement of this travel is indicated by the diagram at Fig. 2. When a turn is being made, the ball will be acted upon by centrifugal force as well as by the force of

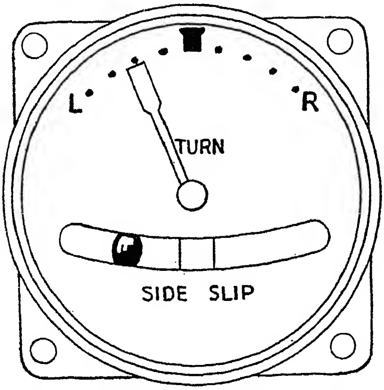


Fig. 4.—AN OVERBANKED TURN.

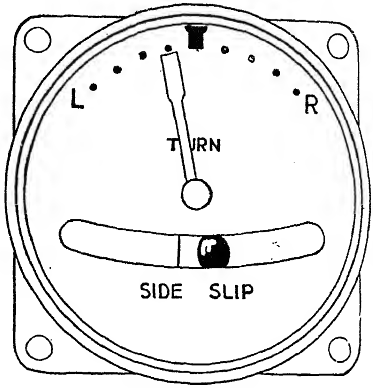


Fig. 5.—SLOW FLAT TURN.

gravity if the turn is banked; a correct bank would keep the ball in the centre of the scale, between the two upright marks; at that point the outward and upward pull of the centrifugal force due to the turn exactly balances the downward pull of gravity due to the bank. This is shown by Fig. 3.

If the bank were too steep, the ball would tend to run downhill, as Fig. 4; and in time would reach the lower end of the tube. On the other hand, a flat turn or a turn with insufficient bank will result in the ball creeping along the upper arm of the tube, as shown by Fig. 5.

This instrument, like the two-needle Turn Indicator, can be used for the teaching of spinning and makes an instant recovery when the spin is over. The indication given during a spin is shown in Fig. 6.

Drives for Commercial Turn Indicator

Like any other air-driven Turn Indicators, the drive can be derived in the following ways :—

(1) By means of Venturi tube illustrated in Fig. 7.

(2) By suction from the induction pipe, a method much used in America and on the Continent. The leakage of air is almost infinitesimal and experiments show that there is no effect upon the slow running of the engine.

(3) By means of a suction pump which might be driven by a windmill, a small independent electric motor, or, as at present

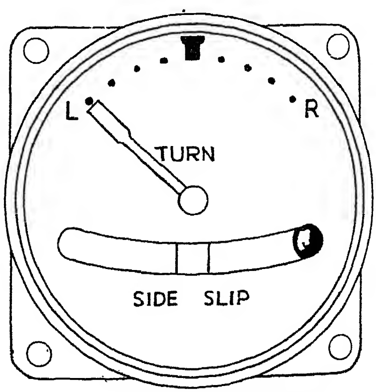
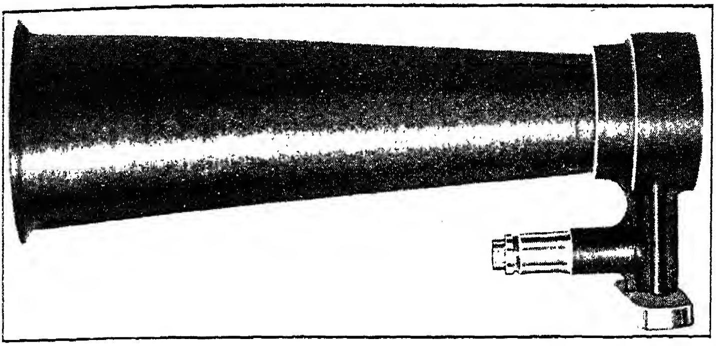


Fig. 6.—SPINNING TO LEFT.

Direction of flight.



Direction of air flow.

Fig. 7.—THE VENTURI HEAD.

The air supply to the turn indicator is usually from a Venturi head of this type.

For Service use, the Venturi is finished black stove enamel, but for civil aircraft it can be obtained in chromium-plated finish if desired.

The Venturi is fitted with the *small* end forwards; and the air flow in at the small end, and out at the large end, must not be interrupted by struts or other obstructions either in front of, or behind, the Venturi. It should point directly into the air-stream.

planned, by being coupled to suitable gearing on the main engine.

The air flow can be adjusted by means of a sensitivity control, illustrated and described on p. 231.

The dimensions of this instrument are exactly the same as the Gyorizon, and are :—

The weight is	1 lb. 4 oz.
Size of case	$3\frac{3}{4}$ in. diameter
Size of dial	$3\frac{3}{8}$,, ,,
Depth behind the dashboard . . .	$3\frac{3}{4}$,,

THE REID FORE AND AFT LEVEL

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

In the early days of flying, pilots judged the pitch of their aeroplane by reference to the air speed indicator or the revolution indicator, since the engine speed would rise, together with the air speed, if the nose of the aeroplane were forced down ; and both would fall if the aeroplane were pulled up into a steep climb. When blind flying instruction became general, some more definite indication of pitch was considered necessary, and the liquid type fore and aft level was developed accordingly. Its purpose is to show not so much a deviation from the horizontal, as to indicate with great accuracy whether or not the aeroplane is flying exactly level—a matter of great importance in thick cloud or fog.

Immediate Indication of Alteration in Pitch

In this, it has an advantage over the air speed or revolution indicators, both of which will show alteration in pitch only after the aeroplane has altered speed as a result. The liquid level shows an alteration in pitch, even momentary, at the same instant at which it occurs ; the other two instruments wait for the result of the alteration in pitch, a time lag of several seconds.

Mounting Space

Counting the mounting space, the instrument takes up on the dashboard a space 1½ in. wide by 5½ in. long and projects behind the dashboard for 5¼ in. ; its weight is only 6 oz. From these figures it will be seen how convenient it is to use this type of instrument either on light aeroplanes—where light weight and small dashboard space are all-important—or on aeroplanes fitted with a large number of instruments, where there may be considerable congestion, both before and behind the dashboard.

For many years this instrument has been used by the Royal Air Force in conjunction with the Reid turn indicator for all blind flying work ; and though in the future a high proportion of Royal Air Force aeroplanes will be fitted instead with a gyroscopic pitch indicator, the liquid fore and aft level is still an essential instrument in small aeroplanes where small dashboard space, light weight and low cost are important considerations.

In view of the great importance of the readings on either side of the centre of the scale, the Reid pitch indicator is provided with a specially

shaped tube which gives a very open scale between zero and 5 degrees, the rest of the scale being relatively less important.

The Instrument

The general appearance of the instrument is clearly shown in Fig. 1. It consists of a closed "U" tube mounted in a bakelite case; the "U" tube is provided with a reservoir at one end, while the third leg of the triangle is flattened in order to provide a wide and clearly visible column of liquid.

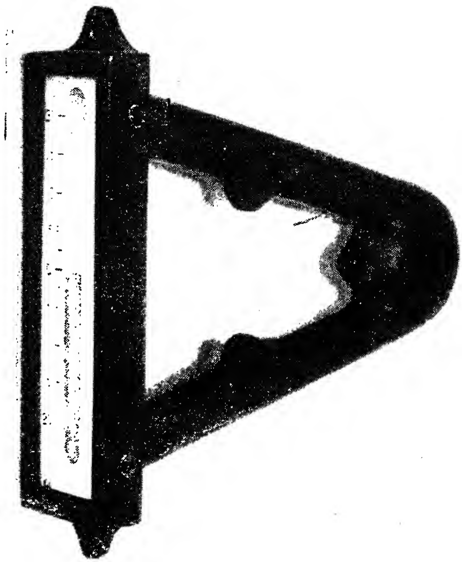


Fig. 1.—THE REID FORE AND AFT LEVEL.

The Indicating Liquid

Half of the interior volume of the tube is filled with the indicating liquid, either pure ethyl or methyl alcohol entirely free from acetone. The liquid is coloured by means of a dye so permanent as to retain its depth of colour even in the tropics; the Royal Air Force prefer that this dye shall be black, but the pitch indicator can also be supplied with a red dye and this is more generally used on the Continent. Not only is the liquid to be fadeless, but it must also be non-staining and during its life or at least during the first five years, it must not mark the tube in which it is contained: it is tested at — 60° C. to make sure that it is non-freezing.

For night flying, the back of the indicating part of the tube is heavily luminised by a line drawn its full length and the zero mark is also luminised; the liquid obscures a proportion of the luminising so that the angle in relation to the zero can be clearly seen in the dark.

The Scale Markings

The glass tube is mounted in a bakelite casing as shown in Fig. 1. The front of that moulding provides a base for the ivorine scale, the markings on which are shown by the illustration. It will be noticed that one side of the scale has been left blank, so that any pilot may register, if he wishes, the angles for cruising, stalling or gliding without engine, which differ with each type of aeroplane.

To mark these angles the screws at the side of the dial are removed, the glass taken out, and the lid replaced. On a test flight, the position of the liquid is marked at the various attitudes of the aeroplane when

flown with and without engine. After the flight the glass is replaced and the pilot will then always have an indication of the best angle for any particular manœuvre.

Testing the Fore and Aft Level

The preliminary tests are carried out at room temperature between 10° C. and 20° C. It is permissible to tap the instrument lightly during its test, to simulate the slight dashboard vibration when the engine is running. A number of instruments can be tested at once by means of a jig and the zero position in each of them must be indicated when both the sides and the back of the front flange are truly vertical.

Each instrument is then tested for damping; it is mounted on a small piece of wood hinged to a baseboard, the hinge being about ½ in. from the bottom of the instrument—that is, from the bottom fixing hole. The instrument may then be tilted backwards or forwards to obtain various readings. It is then tilted forwards to read 15 degrees above zero and allowed to fall back under the action of gravity, when the time taken for the liquid to reach a steady indication of about 20 degrees below zero shall not be less than 1·8 seconds nor greater than 2·2 seconds.

The permissible errors in range are plus or minus 0·5 degree at the zero position, plus or minus 1 degree between 0 and 10 degrees, and plus or minus 2 degrees between 10 and 20 degrees. This is tested by a scale of degrees fitted to the jig previously mentioned.

Fitting the Pitch Indicator

The aeroplane is first placed in flying position; if there is a sloping dashboard it will be necessary to provide a backing piece in order that the face of the pitch indicator shall be absolutely vertical.

When a truly vertical base has been obtained, a hole in the dashboard is cut 4½ in. long by ⅞ in. wide, the instrument slipped in and screwed down when the liquid indicates the exact zero.

If the pilot wishes to carry out the procedure of marking the various angles of climb or dive, as detailed in an earlier paragraph, the instrument may be screwed to the dashboard on the first occasion after the glass has been removed; otherwise it will be necessary to take it off the dashboard in order to remove the bakelite lid.

THE REID DIVE-BOMBING INCLINOMETER

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

A LIQUID fore and aft level, such as that previously described, is a suitable instrument to indicate a deviation from level flight; and since this is its primary purpose, it does not matter very much that the scale is confined to no more than 20 degrees above or below the horizontal. If the aeroplane is pulled into a steeper climb than 20 degrees, the liquid will fill the front tube and give no useful indication of the climbing angle, except to show that it exceeds 20 degrees; similarly, if the aeroplane is forced into a steep dive, the liquid will disappear at the bottom of the scale.

It would of course be possible to make a semicircular liquid level which would read all angles of climb or dive, but the reading at steep angles would be in an awkward position from the pilot's viewpoint; thus in a 90 degrees dive the liquid would be standing at the point where the semicircular glass tube meets the dashboard.

Importance of Reading of Steep Angles of Dive

In recent years the reading of steep angles of dive has become of much greater importance in connection with diving bombing; and a simple form of dive-bombing inclinometer was therefore evolved by Squadron-Leader G. H. Reid to indicate all angles of dive or climb.

The Instrument

It consists of an oil-damped circular pendulum swinging according to the angle at which the weighted part of the pendulum is deflected by gravity in relation to the case of the instrument. The close-fitting transparent-fronted case is provided with a datum line; and when the aeroplane is flying level the zero of the circular pendulum will be against that datum.

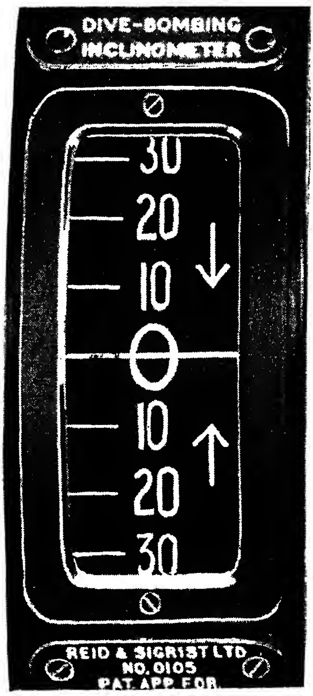


Fig. 1.—The Reid Dive-Bombing Inclinometer.

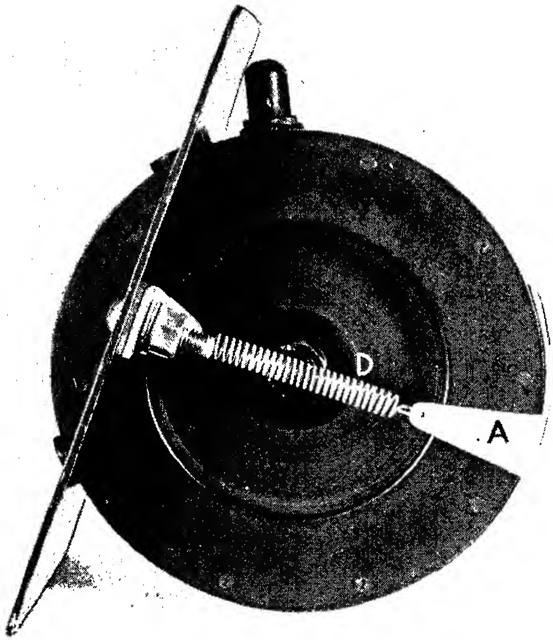


Fig. 2.—SIDE VIEW OF THE DIVE-BOMBING INCLINOMETER.

On any departure of the aeroplane from level flight, as when the pilot forces his aeroplane into a dive or climb, the pendulum swinging in relation to the case indicates in degrees the angle of climb or dive as soon as the aeroplane has settled down on to its new course. A series of arrows show whether the aeroplane is going up or down in relation to level flight. The damping is such that the indicating dial settles to any new reading almost instantaneously; and provision has been made, by means of a diaphragm within the instrument, for the expansion or contraction of the oil, in order to avoid the possibility of an air bubble.

Dimensions and Weight

Fig. 1 shows, practically full-size, the small amount of dashboard space taken up by the instrument, which is most compact. The case is the shape of a cylinder, narrow in height as compared with the diameter; and when this flattened cylinder is set on edge with the dial protruding through the dashboard, the space taken up behind the dashboard as well as in front is very small. In order to fit it for immediate attachment to dashboards which slope at varying angles in relation to the fore and aft line of the aeroplane, a special spring mounting has been devised and forms part of every instrument supplied.

The weight of the instrument is $10\frac{1}{2}$ oz. Its dimensions bare are as follows :—

Diameter of case	$3\frac{3}{4}$ in.
Width of case	$1\frac{3}{4}$ in.

When the instrument is fitted with its spring mounting, an extra space is taken up on the dashboard, amounting to an addition of $\frac{1}{2}$ in. on either side of the dial illustrated.

Instructions for Fitting

The instrument is supplied with its front plate temporarily affixed to a template representing the dashboard. Fig. 2 shows a side view of the complete instrument and the springs attaching it to this template. The holder A is to be moved round until the instrument can be detached from the front plate ; the template can then be removed.

Using the aperture in this template as a model, a hole in the real dashboard is cut to the same size ; and the template can also be used to fix the position of the screw holes.

From the front of the dashboard the holder A and the spring D can now be inserted by twisting them a little sideways, and the screws inserted. Then with the holder A at its lowest position, the inclinometer itself can be inserted from the back of the dashboard. Holder A must then be moved back again to the position shown in the photograph.

The aeroplane is next placed in flying position with the tail on a trestle, and it is usual to confirm by means of a spirit level that the attitude of the aeroplane is exactly the same as in level flight. The dive-bombing inclinometer should then show zero ; but if the dashboard is a sloping one or for any other reason the zero is not correct, it is possible, by hand and by temporarily easing the pressure of the holder " A," to twist the body of the inclinometer round in either direction until the zero is correctly indicated.

QUESTIONS AND ANSWERS

What is the Reid Dive-Bombing Inclinometer ?

An instrument for indicating steep angles of dive or climb which cannot be indicated by the normal liquid fore and aft level.

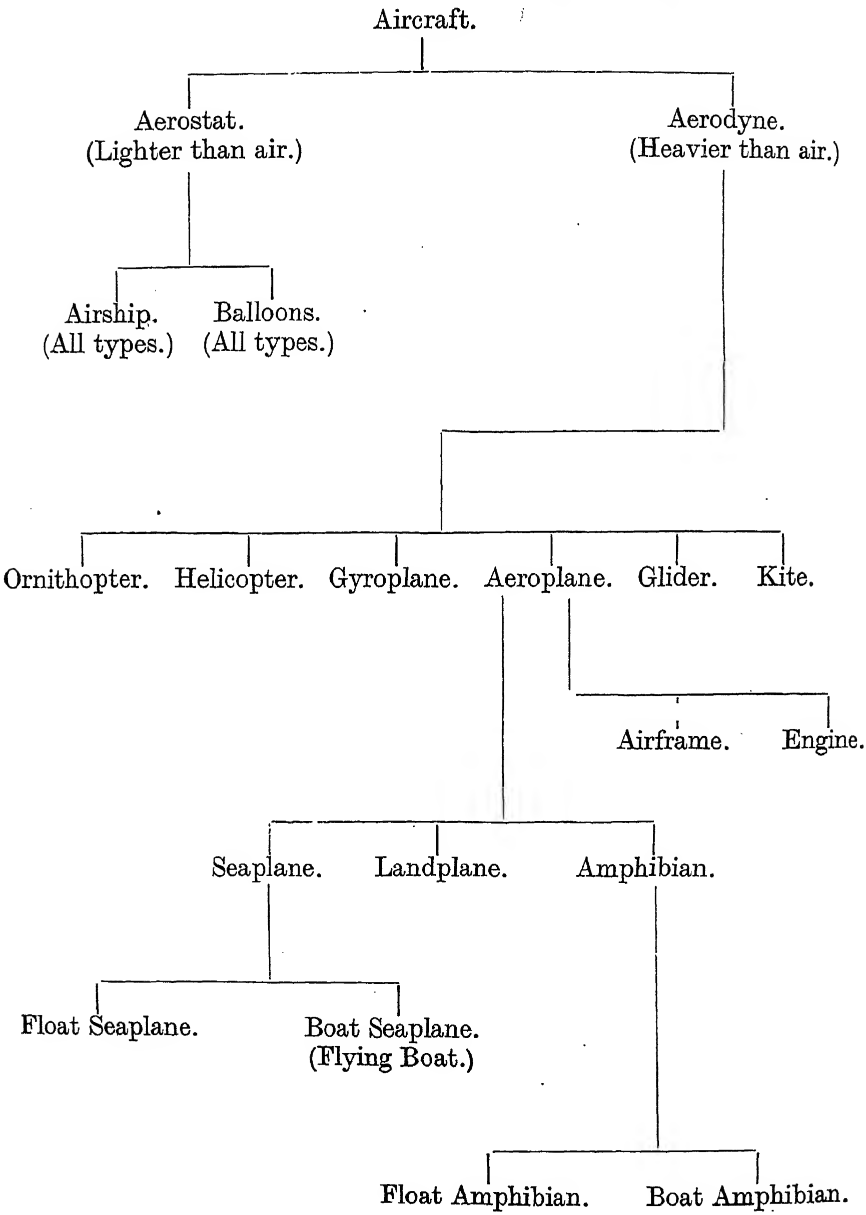
Describe its Construction

This instrument consists of an oil-damped circular pendulum swinging according to the angle at which the weighted part of the pendulum is deflected by gravity in relation to the case of the instrument. The close-fitting transparent-fronted case is provided with a datum line ; and when the aeroplane is flying level, the zero of the circular pendulum will be against that datum.

What Provision is made against the Possibility of an Air Bubble Forming in the Inclinometer ?

There is a diaphragm within the instrument, for the expansion or contraction of the oil.

NOMENCLATURE



OF AIRCRAFT

Aerodyne.—Aircraft which derive their lift from aerodynamic forces.

Aeroplane.—A mechanically driven aerodyne with fixed wings.

Aerostat.—Aircraft supported by their buoyancy.

Aircraft.—All types of air-borne craft.

Airframe.—An aeroplane with the engine or engines removed.

Airship.—A mechanically driven aircraft which derives its lift from buoyancy.

Amphibian.—An aeroplane provided with the means of rising from or alighting on either land or water.

Balloon.—An aerostat not mechanically driven ; rigid, semi-rigid or non-rigid.

Boat Amphibian.—An amphibian whose hull is also a means of support on water.

Boat Seaplane.—A seaplane whose hull is also a means of support on water.

Engine.—The means of providing the motive power.

Float Amphibian.—An amphibian with floats for arising from and alighting on water.

Float Seaplane.—A seaplane provided with floats for rising from and alighting on water.

Glider.—An aerodyne not mechanically driven, but with fixed wings.

Gyroplane.—An aerodyne in which support in flight is obtained by revolving aerofoils or rotors.

Helicopter.—An aerodyne for vertical ascent obtained by the reaction of the air on rotors.

Kite.—An aerodyne not mechanically driven but anchored or towed by a line.

Landplane.—An aerodyne provided with means for rising from or alighting on land.

Ornithopter.—An aerodyne whose support is obtained by the reaction of the air on wings which are flapped mechanically.

Seaplane.—An aerodyne provided with means for rising from or alighting on water.

THE DEVELOPMENT AND DESIGN OF IGNITION SCREENING HARNESS FOR AERO ENGINES

By W. F. Bubb

THE interference caused by the ignition system of aero engines has been a source of trouble since the early days of aircraft radio.

Each time a discharge occurs across the gap of a sparking plug, a highly damped wave train is radiated, which shock excites the radio receiving circuits and causes interference with reception.

Telegraphic reception is, for obvious reasons, impaired to a less degree than telephonic reception, as, in the latter case, intelligibility as well as audibility of signals may be affected. On medium wavelengths suppression of the interference, though desirable, is not always essential either for telegraphic or telephonic reception, but with the growing popularity of aircraft direction finders and of short wave services for long distance commercial and small military aeroplanes, suppression is fast becoming a necessity.

The Only Complete Cure for Radio Interference

Interference varies greatly in different types of aeroplanes and with different equipment, often for no obvious reason. It can be mitigated by careful placing of the aerial leads, or by screening only the switch leads running back from the magneto to the cockpit, but the only certain cure is complete shielding or screening of the whole ignition system, including the leads to the starting magneto when one is fitted.

The terms shielding or screening as applied to this work mean housing the entire ignition system within a bonded and earthed metal sheath, and so confining the electrical fields which otherwise would be radiated in much the same way as from a series of low-powered "spark" transmitters connected to aperiodic aerials.

Mechanical and Electrical Difficulties

It is more easy to satisfy the radio requirements in this respect than to overcome all the mechanical and electrical difficulties which arise.

The reliability and performance of the engine must not be prejudiced in the slightest degree, and maintenance problems must receive very careful consideration.

The modern screening equipment for an engine is commonly termed a harness, and it is the aim of the harness designer to produce an equipment which is not only efficient from the radio and electrical point of view, but which will actually protect the ignition equipment from mechani-

cal damage and subsequent electrical breakdown. A harness meeting this requirement finds favour with the engine manufacturer and maintenance engineer who have a natural objection to the addition to engines of anything complicated, fragile, or heavier than need be.

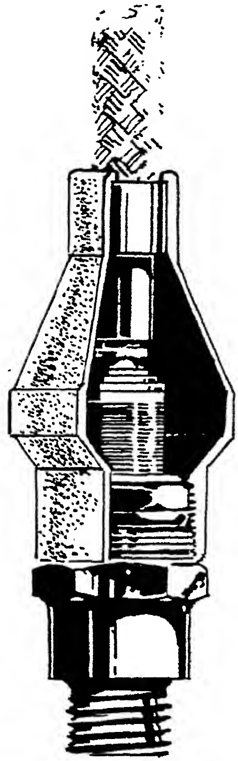


Fig. 1.—THE K.L.G.-MARCONI PLUG AND SCREEN.

Interference Caused by Faulty Bonding

The term "bonding" as applied to aircraft radio practice means that metal parts are interconnected through a path of low electrical resistance and connected to "earth." By "earth" is meant the main metal mass of the aircraft which should be thoroughly "bonded" throughout. This mass is used for the wireless earth, and if there is uncertain or intermittent connection between adjacent metal parts, troublesome grating noises will cause bad interference with radio reception.

The noises are caused by small electric charges which build up on isolated metal parts or parts which have only a high resistance or intermittent contact with the main mass.

When the contact resistance varies, due to rubbing action or vibration, the electrical charge builds up and leaks away in an irregular manner, causing bonding noise which must not be confused with ignition noise.

Early Efforts to Eliminate Interference

Before dealing in detail with the modern type of harness, mention will be made of some of the earlier experimental work and troubles encountered.

The first attempts in England, if not in the world, to tackle the interference problem seriously were probably those made by the Marconi Company in 1920 in co-operation with the K.L.G. Co.; a sparking plug was developed with a screening cover which was used in conjunction with high tension cables covered with a closely woven tinned copper braiding.

A number of engines were fitted with this screening equipment with useful results.

Use of Metal Braided Cable Screening

The development of metal braided cable was continued by the British Air Ministry and in its much improved form is still used to-day.

The diameter and weight have been decreased and there is a layer of

varnished cambric under the metal braiding to protect the rubber from the effects of oil and ozone.

Tinned phosphor bronze braiding is now preferred in place of copper, but this type of high tension cable is definitely disliked and distrusted by many of those responsible for maintenance of commercial flying services.

Troubles to Guard Against

The chief troubles appear to be fretting of metal braiding, with the risk of the broken braid wires piercing the insulation, thus causing localised electric stress with consequent breakdown ; also moisture retained by the braiding creeps along to the cable ends, causing bad leakage.

Great care must be taken when preparing and finishing the ends of the cable, otherwise stray ends of braiding may be driven into the rubber.

Similar cable of a smaller diameter is perfectly satisfactory for screening the low tension switch leads running from the magneto to the pilot's cockpit and is used extensively for this purpose.

The Standard System of Screening which has been Superseded by—

The standard system of screening which has been adopted up to this last year by the British Air Ministry calls for screened magneto and braided cable, as described above, carried up to the sparking plugs. The metal braiding at the plug end is connected to the base of the plug by a bonded lead. Switch leads are screened and also leads to starting magnetos. The metal braiding is bonded at least every 18 in.

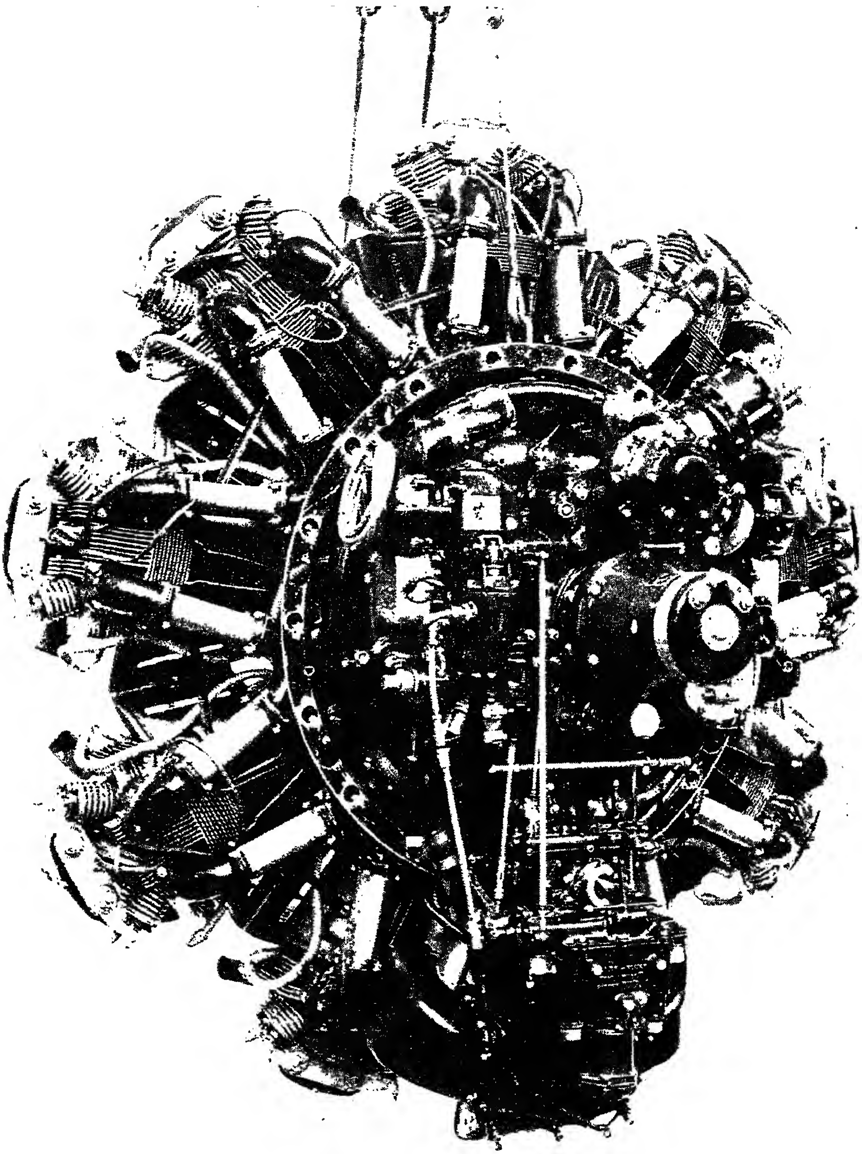
—the Modern Complete Harness

The complete harness, which is now supplanting this system, offers less possibility of maintenance troubles, and at the same time provides the greater screening efficiency required by modern aeroplane wireless apparatus.

The development of the modern harness was commenced in America and the quick development of the American type harness as a safe and serviceable assembly was undoubtedly due to the active co-operation between the American Bureau of Standards with other government departments, research laboratories and manufacturers.

The American Bureau of Standards first evinced interest in shielding experiments in about 1926. The Navy Department later became interested, and in co-operation with an American company developed a shielded plug.

Active work was carried on up to about 1930, by which time sound and practical harness for various types of engines had been evolved. Harness is now available for most types of American engines and there are several large corporations specialising in its manufacture.



[*Bristol Aeroplane Co. Ltd.*

Fig. 2.—LATEST TYPE "PEGASUS" ENGINE FITTED WITH SCREENING HARNESS.

During the course of the experimental work it was found, as indicated earlier in this article, that the difficult part of the problem was to produce shielding equipment which was mechanically and electrically sound, so that the engine reliability was not prejudiced and also sufficiently robust and simple to please the engine people.

Most of the American aeroplanes seen in England are equipped with fully screened ignition systems, and for the few not fitted standard equipment is available if required. Many of the Continental air liners also are so fitted.

The Marconi Company, in co-operation with the Bristol Aeroplane Company, was first to develop and standardise a design which met the Air Ministry's stringent requirements, and is now occupied in bulk manufacture for various types of engine.

Fully Screened Harness for a Radial Type Engine

A description of the detail design and construction of a harness for a radial type engine can best be commenced by listing the components which have to be shielded.

These are :-

(*a*) The main magneto.
(*b*) High tension leads to sparking plugs.
(*c*) Sparking plugs.
(*d*) Magneto switch leads and switches.
(*e*) Starting magneto.
(*f*) Leads for starting magneto.

The whole screening harness must be watertight and oil-proof.

Screening the Magneto

The magneto must be supplied with a metal screen completely enclosing the high tension distributor block. This screen must be made with a tubular outlet or snout to connect to the flexible conduit which carries away the high tension cables from the magneto. It must also be so designed that the distributor block is easily accessible for wiring and inspection.

High Tension Cables

The high tension cables, which should be constructed with ozone-resisting sheathing, are taken from the magneto distributor through a flexible metallic conduit to a main distributing tubular manifold ring. This manifold ring has two large inlets which connect up to the large flexible conduits from the two magneto distributor screens and bring in the high tension cables.

Sparking Plugs

The manifold ring is carried on the engine by suitable metal clips

and has small outlets around its circumference connecting by suitable unions to metal braided flexible metallic tubes, which carry the high tension leads individually to the respective sparking plugs. The sparking plugs are constructed with screening sheaths enclosing the live terminal and the flexible metal tubes are connected by suitable unions.

It will thus be seen that the whole of the high tension system is completely cased in metal, and it is very important that every joint should be clamped metal to metal so that the whole system is completely bonded.

Contact Breaker and Switch Wires

The contact breaker on the magneto should be enclosed within a metal cover.

The switch wires running from the contact breaker to the switches in the pilot's cockpit should be metal braided and thoroughly bonded to earth at each end and at intermediate points.

Auxiliary Starting Magneto

The distributors on the main magnetos are generally provided with a connection to which can be connected a high tension wire from an auxiliary magneto (hand operated) for starting purposes.

It is necessary that this lead also should be screened and thoroughly bonded to the earth.

A metal braided cable may be used for this or a plain cable as used in the main harness may be run in similar flexible metallic tube.

A screening harness for a Bristol "Pegasus" engine is illustrated in Fig. 4.

CONSTRUCTIONAL DETAILS AND POSSIBLE CAUSES OF TROUBLE

Having now given a general description of a harness equipment, the next step is to consider points of detail construction and possible sources of trouble.

The Distributor Screen

We will start again at the magneto. The large flexible metallic tube joining up to the distributor screen should preferably be secured by a large union nut to the outlet snout on the screen. Locking means must be provided.

The flexible tube must have sufficient freedom so that vibration transmitted back from the main manifold ring is damped out and does not tend to "work" the distributor screen.

The interlock type of tube probably is best for this particular job and it should be covered with a tinned phosphor bronze wire braiding to ensure perfect screening.

Aluminium braiding is unsuitable from a mechanical point of view.

Aluminium may be used for the tube itself, but in this case the end

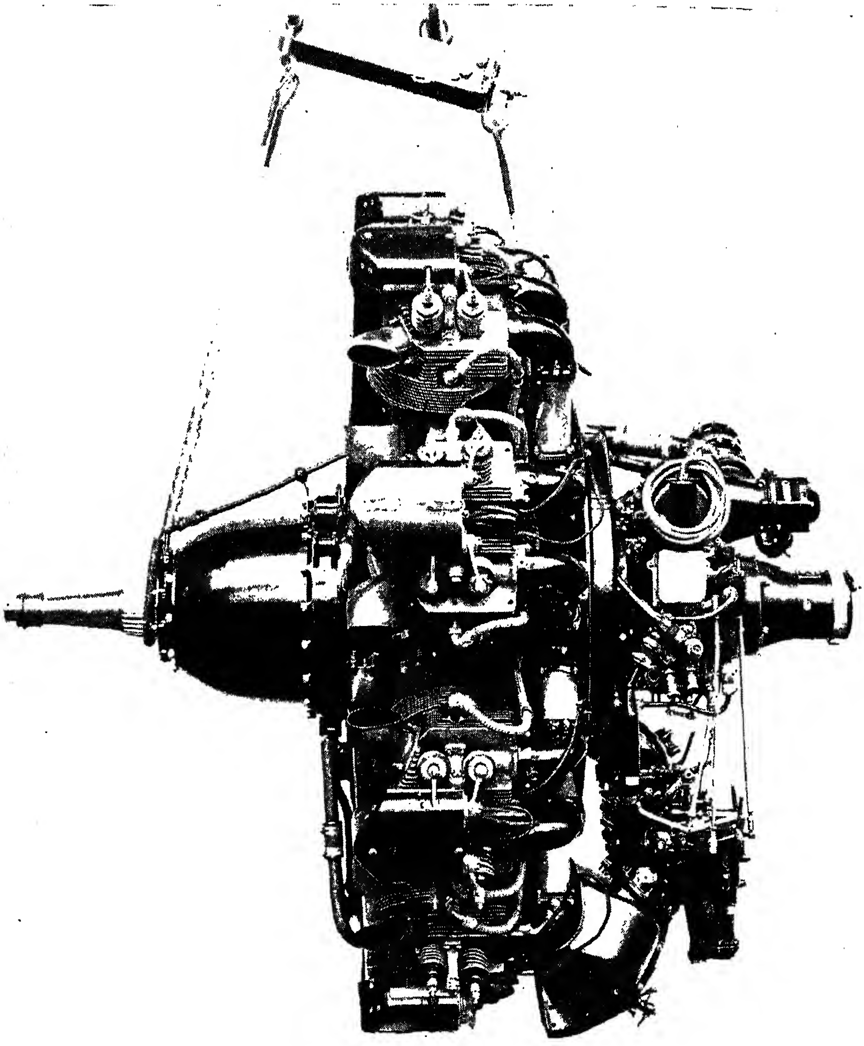


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Fig. 3.—ANOTHER VIEW OF THE SCREENING HARNESS FITTED TO "PEGASUS" ENGINE.

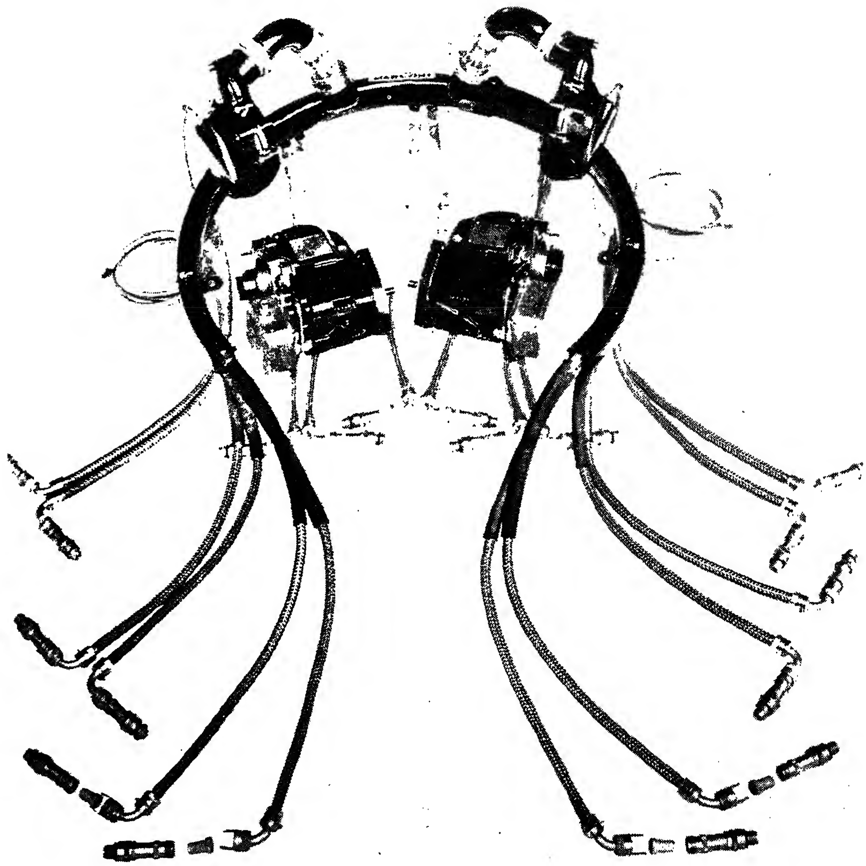


Fig. 4.—MARCONI HARNESS FOR BRISTOL "PEGASUS" ENGINE.

fittings will have to be swaged on. Copper or brass will make a much more satisfactory mechanical and electrical job, although, of course, weight is slightly increased.

The main manifold ring may be made from brass or aluminium. Brass is certainly preferable, and it is not at such a very great disadvantage to aluminium in regard to weight, as a lighter gauge metal can be used.

Fittings can be brazed or silver soldered on and threads are much more robust.

When junction fittings have to be added the greatest care must be taken that there are no sharp or rough edges which can damage the cables when they are drawn in.

Bends should be made as easy as possible.

The large flexible tubes from the distributor screens can probably best be connected up to the fitting on the main manifold tube by a large union nut in the same manner as proposed for its other end.

The unions for the small flexible tubes where they join the main manifold must ensure good bonding and a watertight connection.

The small flexible tubes should be covered with a tinned phosphor bronze wire braiding.

The tube should be capable of taking a fairly sharp bend without trouble developing in service.

At the Sparking Plugs

The union connecting to the sparking plug must make just as good a bond and particularly must be watertight, otherwise trouble will quickly develop in the plug.

The flexibles must be carefully cleated in position so that no strain comes on the plug.

A variety of screened plugs and plug screens have been produced by English, American and Continental makers.

A number of plugs are made with the screening sleeve integral with the body of the plug, in which case the mica lining must be depended upon for the insulation.

Some American manufacturers prefer a type where a large metal cup fits round the live terminal.

In this type sufficient air-space can be allowed for insulation, although an additional insulating lining is sometimes fitted as an additional safeguard.

Several English makers are producing sparking plugs for use with screening harness, notably the K.L.G. Company and Messrs. Lodge Bros.

High Tension Cable

The class of high tension cable developed for use with screening harness has an outer water- and oil-proof covering of lacquered or varnished cambric which also serves to prevent ozone from coming into contact with the rubber insulation.

There is always a chance that a brushy discharge may occur inside the harness, and the ozone thus liberated would quickly play havoc with the rubber insulation of the cables if protection was not given.

One particular make of cable incorporates Thiokol (ethylene tetrasulphide) in the insulating covering under the cambric. This substance has very useful ozone-resisting properties.

The Necessary Shielding for Other Types of Engine

So far we have described a typical harness for a radial engine. Shielding is, of course, just as necessary for a straight " in line " or a " V " type

engine. The difference in make-up is really in mechanical shape only. Similar materials can be used and the same necessities of accessibility, mechanical soundness and good electrical bonding apply.

Inspection and Tests of Harness

Rigid inspection of harness components is necessary to ensure that there are no sharp edges on any fittings which may damage the cables and, of course, the inspection after assembly should be made particularly to note that all unions are properly seated.

Electrical tests should check continuity of leads, electrical resistance from spark plug end of small flexible tubes to any part of main manifold tube or distributor end of large flexible tube (which should not exceed 0·025 ohm.).

High Voltage Test

A high voltage test using a spark coil and a calibrated spark gap should be made to check the insulation of cables. The gap should be set for 15,000 volts breakdown. One side should be connected to one end of each cable in turn and the other side of gap should be earthed to the harness tube assembly. All cables should withstand this test.

Radio Test in Flight

The final test for the goodness of the bonding and screening of the aeroplane is, of course, a radio test, preferably in flight.

A harness made up as described above and carefully installed should permit of satisfactory radio working well down into the ultra short wavelengths, but it must be remembered that should ever a single union work loose and cause a bad bond, a potential can be built up and radiation will take place with consequent noise interference.

Careful inspection and maintenance is essential if the efficiency of the harness is to be maintained.

Eliminating Interference from Dynamos

It may not be out of place to mention here that the ignition system on the aeroplane is not the only offender as regards interference with radio reception.

Charging and lighting dynamos, especially those which may be operating with voltage regulators of the vibrating contact type, can be very troublesome sources of interference.

Radiation takes place not only from the dynamo and regulator, but also from the whole wiring system.

Here again there is only one real cure, and that is enclosing the whole system in screened and bonded conduit with proper bonding unions on the components.

QUESTIONS AND ANSWERS

What is Meant by Ignition Screening?

Housing the entire ignition system within a bonded and earthed metal sheath to prevent unwanted radiation.

What Components of an Aero Engine must be Screened?

(*a*) The main magneto.
(*b*) High tension leads to sparking plugs.
(*c*) Sparking plugs.
(*d*) Magneto switch leads and switches.
(*e*) Starting magneto.
(*f*) Leads for starting magneto.

Does a Modern Screening Harness Serve any Purpose other than the Prevention of Electrical Interference?

Yes. It is designed in such a way that it also protects the ignition equipment from mechanical damage.

What is the Normal High Voltage Test for the Insulation of the Ignition Cables?

15,000.

What is the most Important Point to Watch in Maintaining the Efficiency of the Ignition Screening Harness?

That the electrical bonding of the metallic sheathing is continuous throughout the system.

AUTOMATIC ENGINE CONTROLS

By E. W. Knott, M.I.A.E., M.S.A.E.

When aeroplane engines were of the normally aspirated kind, *i.e.*, not supercharged, or "blown" to use a trade expression, they required relatively little care and unless of the high compression type full throttle could be given at ground level. The advent of the "blower", however, while giving extraordinary improvement in performance, brought with it a host of responsibilities to the pilot in whose care the engine was entrusted. Each year sees the same engine giving more power with a smaller specific consumption and this means that the engine requires more skilful and continuous attention if its normal life is to be maintained.

The blower was the logical answer to the gradual loss of power as the engine gained altitude, the loss being due to the increasing lack of the oxygen necessary to burn properly the liquid fuel supplied to it. By using the blower to force air into the engine, the power developed at ground level could be maintained up to a given height, the height being known as the rated height, full throttle height or critical altitude, according to the various country of origin. An engine with a blower that will sustain ground atmospheric pressure up to say 10,000 ft. is known as a 10,000 ft. engine, and it is obvious that with such an engine if the throttle is opened fully at ground level, the compression pressure and thereby the explosion pressure will rise far above normal, with disastrous results.

In the early days of supercharged engines the pilot's throttle lever had a "gated" quadrant; in other words, a series of stops was provided to limit the throttle opening, each corresponding to a safe induction pipe pressure. So long as the pilot observed this, the engine was safeguarded, but abuse of this simple device caused the early destruction of countless engines. With civil aeroplanes, flown under conditions where the pilot had time to observe his instructions, the "gated throttle" was fairly satisfactory, but for military aeroplanes where rapid changes in altitude took place, the pilot had too much to do, with the result that engines were either wrecked or had their life seriously shortened.

Induction Pressure (Boost) Controls

The first step to relieve the pilot of the responsibility for his engine boost pressure was the invention of the boost control. This was a device, using engine oil pressure for its motive power, which took the control of the carburetter throttle opening from the hands of the pilot. Interposed between the carburetter throttle and the pilot's throttle lever was some linkage controlled by the boost control in such a fashion that if the pilot opened his throttle lever further than the altitude called for, the

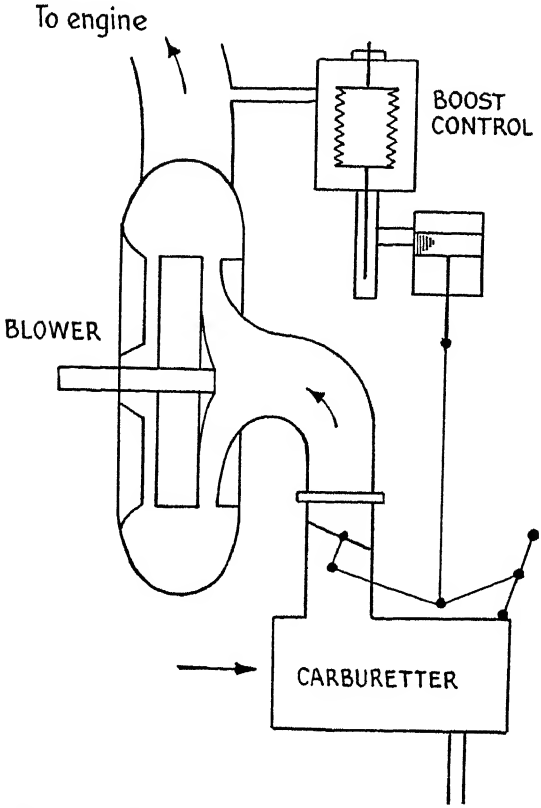


Fig. 1.—ONE WAY OF APPLYING A BOOST CONTROL.

boost control took charge and limited the carburetter throttle opening. This device was adjustable and it was possible to keep the induction pipe pressure constant up to the height to which the blower could sustain ground atmospheric pressure. At this altitude the carburetter throttle is fully opened and unless the aeroplane is dived at a speed where the airscrew forced the engine to a speed where the boost pressure goes beyond normal, the boost control remained inoperative until the aeroplane begins to descend below rated height.

For some years all supercharged (blown) engines in Great Britain have been fitted with boost controls, and foreign countries are beginning to recognise their benefit and are rapidly adopting them. Thus one responsibility was taken from the heavy load imposed on the pilot, with marked benefit to the engines and to the reputations of the firms who built them.

Figure 1 shows diagrammatically one way of applying a boost control. The control itself consists of an airtight chamber connected to the pressure side of the blower and containing a stack of capsules, such as is commonly used in a barometer. These capsules are connected to a piston valve which moves in one direction or the other, depending on whether the capsules expand or contract under the influence of changing boost pressure. Movement of the piston valve admits high pressure oil from the engine to one side or other of a piston, known as the servo-piston, and this piston operates the linkage interposed between the pilot's throttle lever and the carburetter throttle lever.

The construction of the piston valve and the servo-piston is such that under stable running conditions the valve tends to shut off the oil supply to both sides of the piston and thereby keeps it stationary. This

is known as the "sensitive" position of the valve. If, due to change in altitude, engine load or speed, or change in throttle opening by the pilot moving his throttle lever, the induction pressure changes, the capsule will change in length, thereby moving the piston valve. This, in turn, will allow oil to flow to one side or other of the servo-piston which, in turn, will alter the carburetter throttle opening until the induction pipe pressure once more returns to its original figure. It will be seen therefore that as the aeroplane climbs from the ground to its rated height (the height where full throttle opening gives ground atmospheric pressure) the throttle will be gradually opened, the controlling factor being induction pipe pressure, which keeps constant.

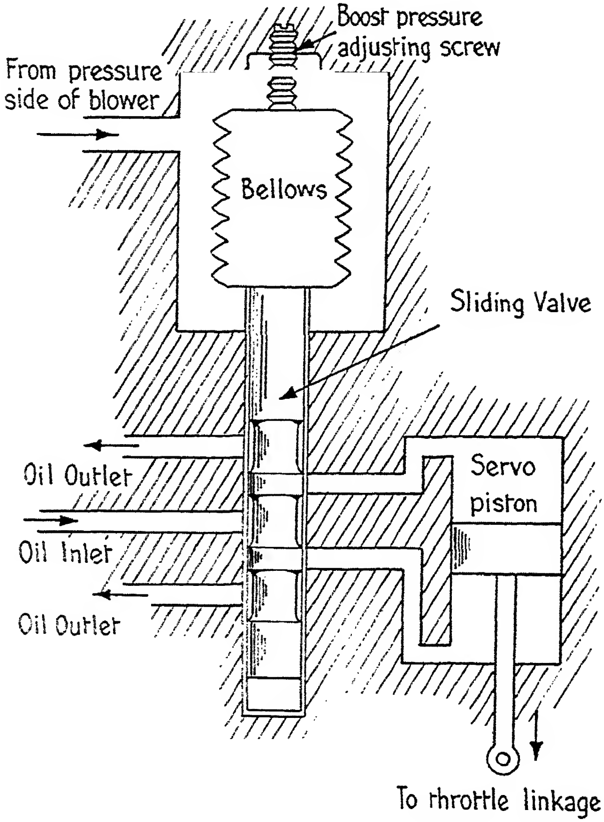


Fig. 2.—SHOWING THE PARTS OF A BOOST CONTROL.

Once the engine reaches its full throttle height, any increase in altitude will cause a fall in power as the blower can no longer sustain any higher pressure. From there onwards a steady drop in power will take place until a height is reached where the power output of the engine is insufficient to lift the aeroplane any higher. This height is known as the aeroplane's ceiling.

Figure 2 shows diagrammatically the capsule, piston valve and servo-piston and Fig. 3 shows how, although the pilot has opened wide his throttle on the ground, the boost control has taken charge of the carburetter throttle opening. Figure 4 shows a power output curve for an engine supercharged to 10,000 ft.

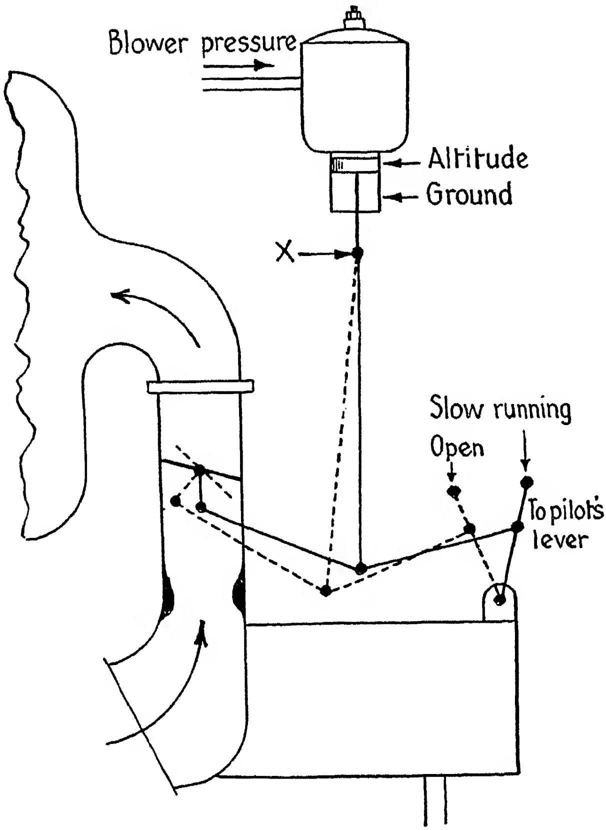


Fig. 3.—BOOST CONTROL IN SLOW-RUNNING POSITION.

It will be noticed that the power increases as the aeroplane climbs to its rated height. Thereafter the boost control can do no more and the carburetter throttle responds to the pilot's throttle lever as with a normally aspirated engine, the linkage pivoting about the point "X" (Fig. 3). The increase up to rated height is due to the reduction in back pressure on the engine exhaust outlets, and in this case after 10,000 ft. the power drops steadily with further increase in altitude. It is this variation in exhaust back pressure that makes the calibration of automatic mixture controls so difficult at ground level, as except by the use of large and expensive plant—of which there are only about five in the whole world—altitude (and temperature) conditions cannot be exactly reproduced.

Several types of boost control are made, the direction of movement of the piston from "ground" to "altitude" varying according to the layout of the linkage. Fig. 5 shows a boost control in the slow-running condition (movement of piston opposite to Fig. 3) and Fig. 6 shows it controlling at normal boost ground level, the carburetter throttle being partly shut although the pilot's lever is fully open.

In actual practice it is found desirable to keep a small quantity of oil circulating through the boost control to prevent freezing or sluggish action due to cold. It is customary therefore to have a small leak hole in the servo-piston of approximately $\frac{3}{4}$–$1\frac{1}{2}$ mm., so that in order to keep the pressure on the piston steady the piston valve must be slightly off the sensitive position. It has also been found that on rare occasions if the

valve was in the sensitive position, the boost control was inclined to surge, in other words the throttle was opened and shut with a rhythmic action. By having a leak hole in the piston, this was overcome and is a legitimate method of curing surge. Too large a hole, however, causes loss of pressure on the piston, which means loss of power and the hole should never be larger than 1½ mm., working oil pressure and temperature being the deciding factor of the size.

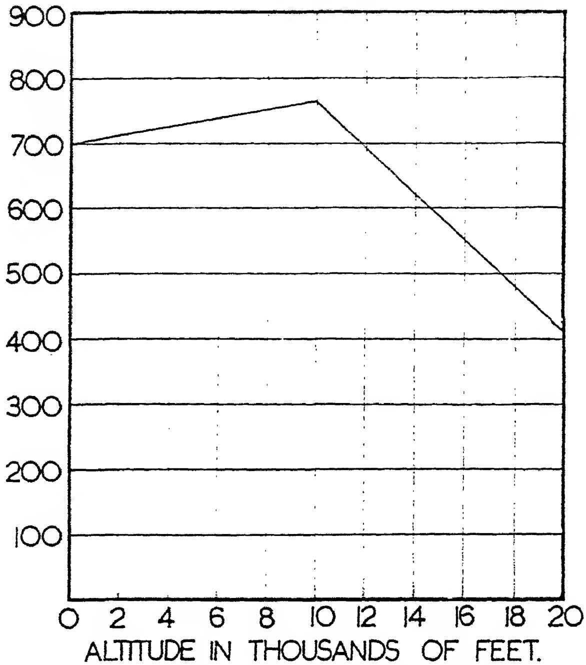


Fig. 4.—A POWER OUTPUT CURVE FOR A 10,000 FT. ENGINE.

Surging can also be caused by the following :—

1. Too small a connecting pipe between the blower and the boost control.
2. Play or wear in the linkage.
3. Tight spots in the linkage so that it is free in one position and tight in another.
4. Air in the oil pipe line.
5. Intermittent slip of the supercharger clutch.
6. Blower surge.

Adjusting the Boost Control

With the engine at correct temperature, the throttle should be opened up slowly until slightly more than the required boost pressure is obtained. The adjusting screw should then be unscrewed until the boost pressure drops to the required figure and the screw then locked. The pilot's throttle should then be capable of being opened fully without the boost pressure exceeding the set figure. If the pilot's lever can be opened fully without the boost pressure reaching the required figure, the adjusting

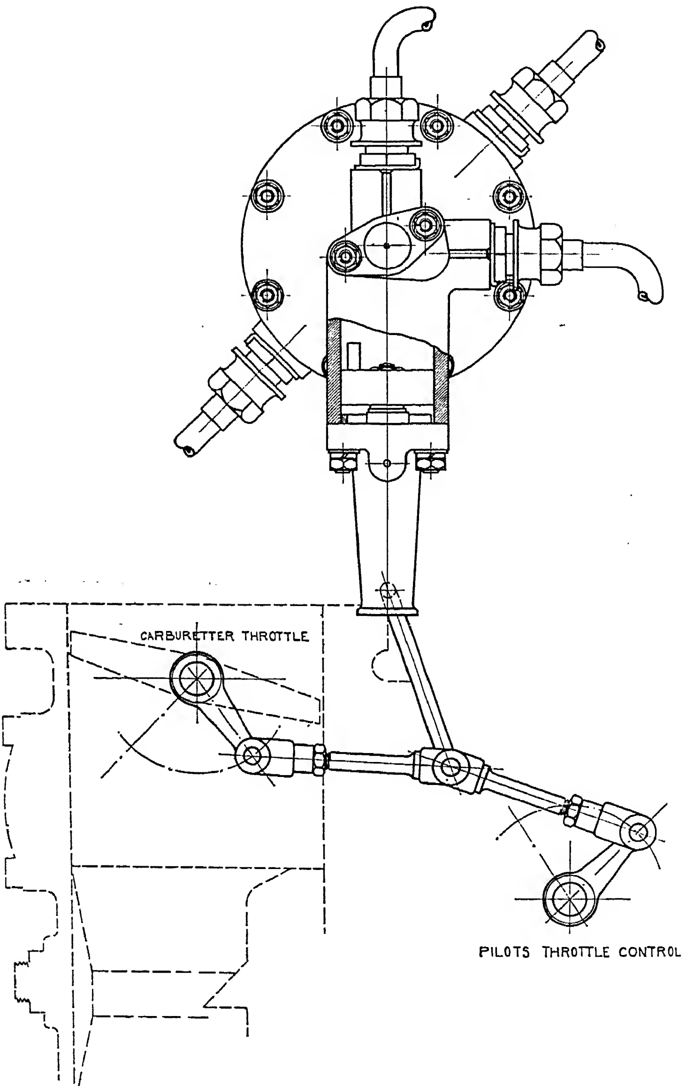


Fig. 5.—SERVO PISTON IN "ALTITUDE" POSITION.

screw must be screwed in (clockwise) until the correct boost pressure is indicated.

Boost pressure is describ- It may be described in inches or millimetres of mercury absolute, which is normal atmospheric pressure plus or minus the pressure in the induction pipe. Such an example would be 760 + say 100mm. of mercury (Hg.). On the other hand, the pressure may be read off the boost pressure gauge in pounds per square inch. If the pressure is equal to the atmosphere, it is said to be zero or nought boost; if above, the boost is said to be (for example) plus 4 lbs. and if below atmospheric (for example) minus 2 lbs. boost. An engine supercharged to only 5,000 or 6,000 ft. would be described as a low supercharged engine, while one supercharged to 12,000 or 14,000 ft. would be described as a high supercharged engine. Beyond this height a single blower begins to get inefficient and if it is

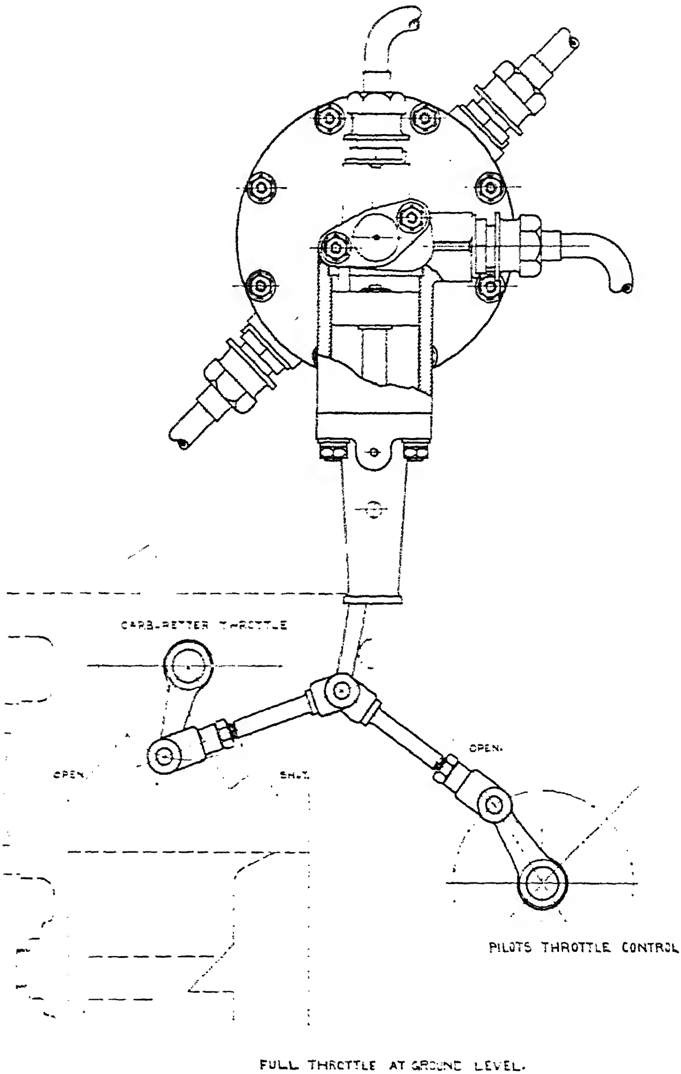


Fig. 6.

required to maintain ground atmospheric pressure in the induction pipe much beyond this height, two-stage or two-speed blowers are necessary. This degree of supercharging heats the mixture to an extent where expansion causes loss of filling of the cylinders which somewhat negatives

the effect of the additional supercharge. Intercoolers become necessary and as the higher temperature may cause detonation, special fuels may also be necessary with two-stage blowers.

Throttle Curves on Supercharged Engines

Assume a supercharged engine "blown" to 10,000 ft. and on which it is not permissible to open the throttle at ground (sea) level more than 25 degrees out of a total opening of 75 degrees. This 25 degrees opening will correspond to a certain boost (induction pipe) pressure; the boost control has been adjusted to maintain this pressure and will hold the carburetter throttle at 25 degrees from the slow running position. Assume the engine to be ticking over slowly. If the pilot's lever is opened up slowly, the engine will speed up until the boost pressure reaches the figure corresponding to 25 degrees throttle opening, the linkage up to this opening being mechanically operated by the pilot's lever, which means that with the pilot's lever 25 degrees open, the carburetter throttle lever will be 25 degrees open. This is the point where the boost control takes charge and any further movement of the pilot's lever beyond 25 degrees has no effect on power output. In effect the pilot can leave his lever anywhere between 25 degrees and 75 degrees without change in power.

If, therefore, the aeroplane is flown near the ground at 25 degrees throttle opening and the pilot wishes to cruise at a lower and more economical speed, he must be able to close the carburetter throttle a few degrees and cut out his power jet. If, as is done in some carburetters, the power jet opening is *mechanically timed off the throttle opening*, it would be necessary to have the power jet come into action at, say, 20 degrees. Let us see what happens as the aeroplane climbs to, say, 5,000 ft. The air is rarer and the boost control will have opened the throttle steadily to say, 50 degrees in order to maintain ground atmospheric pressure. Full power (with power jet in action) is represented therefore by 50 degrees carburetter throttle opening and any opening not less than 50 degrees of the pilot's throttle lever. Similarly, any position of the pilot's lever between 50 degrees and 75 degrees will not cause change in power as the boost control is in charge of the carburetter throttle opening.

If now the pilot wishes to cruise at lower speed, he will have to close his throttle a few degrees below 50, but as the power jet has been set to cut in and out at 20 degrees, he cannot cut it out by a few degrees less opening and is compelled to cruise on a full-power mixture strength, which means that he is using unnecessary fuel and reducing the range of the aeroplane. Similar remarks apply to 10,000 ft. conditions where both the carburetter throttle and the pilot's throttle lever must be 75 degrees open to obtain full power. There again it will be impossible to close the throttle slightly and cruise on an economical mixture as the power jet

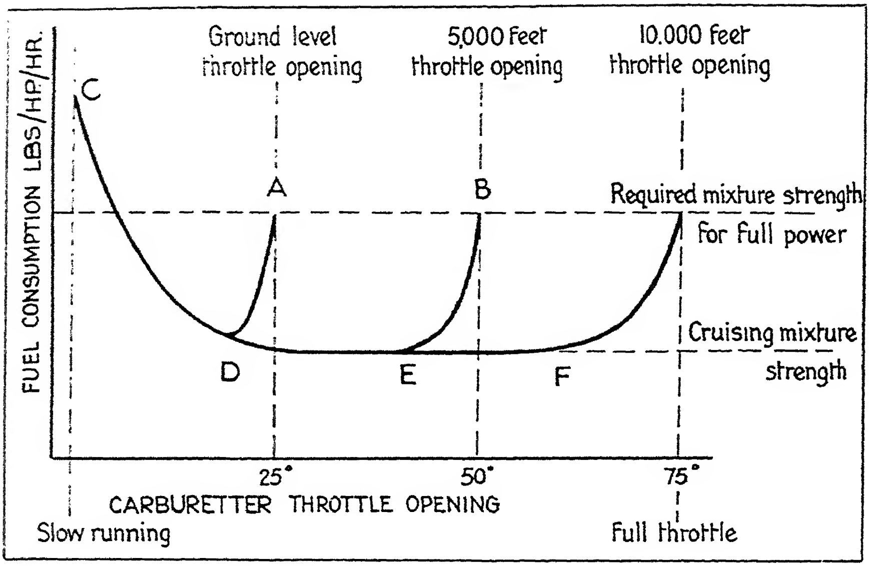


Fig. 7A.—TRAVERSING THE POWER JET.

comes in at a fixed 20 degrees from slow running, and to be able to cruise economically at any altitude, it is obvious that the time when the power jet valve must be opened and closed must vary and this is known as *traversing the power jet.*

Figure 7A shows the necessity for this. Curve CDA shows the throttle curve at ground level, the power jet coming into action at D corresponding to 20 degrees carburetter throttle opening. Curve CDEB shows the throttle curve at 5,000 ft. with the power jet coming in at E a few degrees less than 50 degrees. Curve CDEF and then up to full strength shows the throttle curve at 10,000 ft. (rated height) with the power jet coming in at F. The actual relation between full power mixture strength and cruising mixture strength has been exaggerated in Fig. 7A for the sake of clearness and while representing actually what happens is diagrammatic only.

Some short time ago, an invention was patented with the idea of eliminating the lost motion in the pilot's lever below rated height, and incidentally it brought with it several additional advantages. Its action is best described as follows :—

Assume that the boost control has been adjusted to give the correct induction pressure at ground level and that the engine is running under these conditions, *i.e.*, full power on the ground, and that as the *pilot's throttle lever* is slowly and progressively closed from its full open position, the boost pressure adjusting screw is slowly and progressively unscrewed so that the pilot's lever closing is accompanied by a progressive lowering

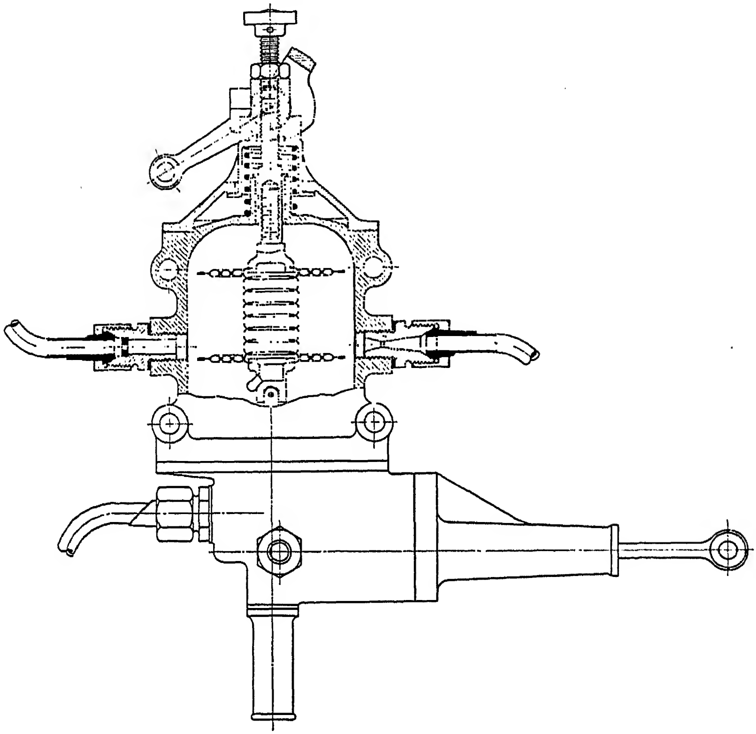


Fig. 7B.—A VARIABLE DATUM BOOST CONTROL.

The lever and cam connected to the pilot's throttle lever can be seen at the top. Only two of the capsules are indicated.

of the boost pressure until it reaches the slow running position. Having reached this position, open the lever under the same conditions, but raise the boost pressure by screwing in the boost adjusting screw. Now substitute for this somewhat cumbersome method of adjusting the boost pressure a cam which will do the same thing, which cam is operated by the pilot's lever.

It is now obvious that full boost at any level between the ground and rated height can only be obtained with the pilot's lever fully open and that each partial movement of the lever will give a change in boost pressure strictly proportional to the angle through which the lever has been moved. In other words the engine behaves like an unsupercharged one, there being no "lost motion" of the pilot's lever.

The obvious thing to do now is to have the opening of the power jet timed by the pilot's lever and not by the carburetter throttle. This cam device is known as a Variable Datum Cam and the boost control using it as a Variable Datum Boost Control. See Fig. 7B.

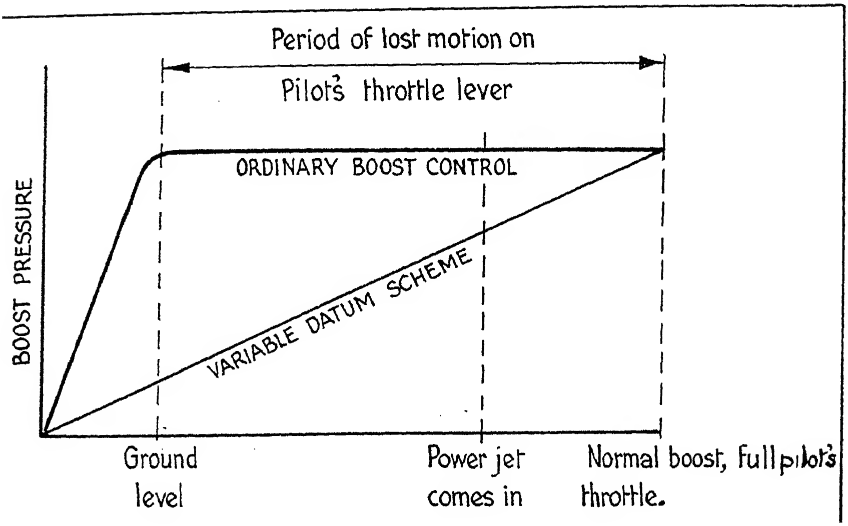


Fig. 8.—DIFFERENCE BETWEEN BOOST PRESSURE CURVES OF OLD TYPE BOOST CONTROL AND THE VARIABLE DATUM TYPE.

Figure 8 shows the difference in the shape of the boost pressure curves for different positions of the pilot's throttle lever.

With the original boost control, the boost pressure at or near ground level shot up suddenly with a relatively small movement of the pilot's lever until it reached rated boost pressure, after which it remained steady irrespective of the position of the pilot's lever beyond the opening corresponding to it. This made exact control of engine speed under certain cruising conditions very difficult and this showed up particularly in formation flying. Also, what was more serious, it was possible to get full power output on a cruising mixture strength, *i.e.*, without the power jet in. Reference to Fig. 8 will show that if the pilot left his throttle lever at any position between that corresponding to ground level and that, just before it opened the power jet valve, full boost is obtained on weak mixture, which means high temperatures and danger of piston seizure.

Comparison with the curve given by the variable datum scheme shows a steady rise in boost pressure and that at the time the power jet begins to feed its extra fuel, full boost has not been obtained. Only when the pilot's lever is as far open as it can go is full boost obtained, and the pilot has under his control an engine extremely flexible in its power control and one with which *at any height* he can always go to economical cruising speeds by closing his throttle lever. This form of boost control has rendered obsolete all previous kinds and its importance cannot be over-emphasised and is the only known method by which the power jet timing can be traversed.

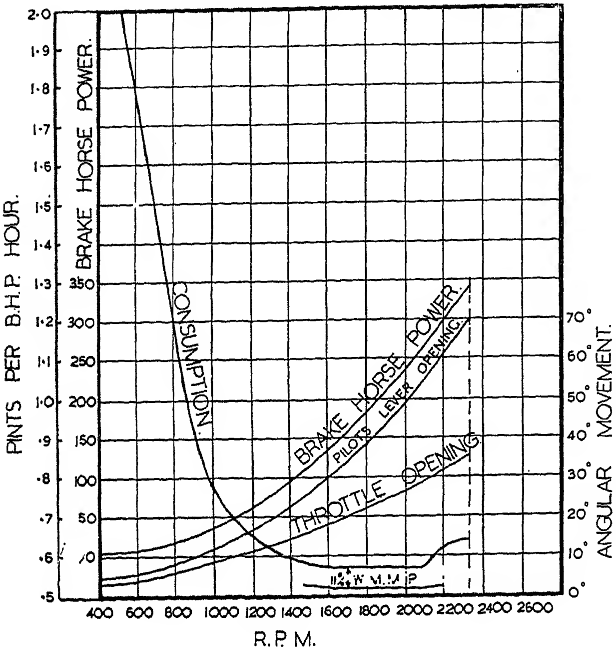


Fig. 9.—THROTTLE CURVE WITH VARIABLE DATUM BOOST CONTROL.

Fig. 9 shows how the power output is strictly progressive with pilot's lever opening. It will be noticed that although normal boost is obtained on the ground with only 35° carburetter throttle opening, the pilot's lever is fully open (70°) and its shape corresponds exactly to the B.H.P. curve. The lowest curve marked W.M.M.P. (weakest mixture for maximum power) should be parallel to the normal throttle curve throughout the cruising range.

Boost pressure is not solely related to power output. Ignition timing and to some extent the control of heat to the carburetter intake are also influenced by boost pressure. With the variable datum scheme, it is of great advantage to control the ignition timing by the pilot's throttle lever, arranging it so that the ignition is retarded for starting and slow running, advanced throughout the cruising range (where it aids economy) and retards it again under full power conditions. Similarly by controlling the hot and cold air intakes or other heating devices, hot air can be supplied during slow running and cruising conditions and cold air at full load conditions.

However, in order that the pilot can avoid ice forming in the induction system when the aeroplane is flying under conditions of severe cold or snow he should have an over-riding device whereby some hot air can be obtained under full load conditions.

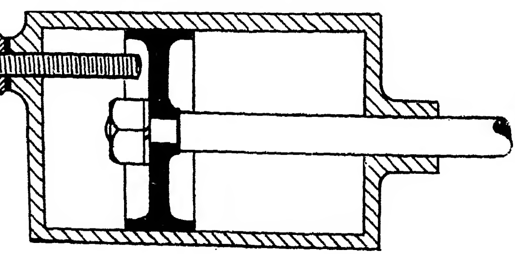


Fig. 10.—AN EXTERNALLY ADJUSTABLE B/C PISTON STOP.

BOOST-CONTROL PISTON STOP

When a boost control is adjusted on the test bench to control the induction pipe pressure to the desired limit (normal boost), the piston will take up a position somewhere between its two extreme limits of movement and will be held there by the oil pressure. Should the oil pressure fail, the piston can move to the end of the cylinder, which means that the linkage will close the carburetter throttle. Any movement of his lever by the pilot will cause the linkage to swing about a point controlled by the piston at the extreme end of its stroke and this means that the carburetter throttle will not open sufficiently to develop enough power for the aeroplane to fly safely. To prevent such a contingency a stop is provided which limits the movement of the piston towards the " ground " position. This stop is adjusted to such a length that it does not quite touch the piston in its normal boost position by approximately $\frac{1}{16}$ in. In earlier models of boost controls this stop consisted of either a washer of the required thickness on the piston rod or a pin riveted in the piston itself, which pin bottomed on the end of the cylinder, but as its length varied slightly from engine to engine of the same type and make, the boost control piston and cylinder had to be " stripped " each time it was necessary to file the pin to the required length. Such a pin is shown in Fig. 6. Later models had an adjustable pin, the length of which could be adjusted with a screwdriver from outside the boost control, and such an adjustment is shown in Fig. 10.

Before adjusting the boost control, the stop should be slackened back so that there is no risk of it limiting the piston movement when it tries to take up its normal boost position. When the piston has settled down, the stop can be screwed in until it touches the piston and then unscrewed to a point where at least nine-tenths ground power can be obtained if the piston is pushed against the stop, thereby ensuring that should the oil pressure fail, the pilot will have sufficient reserve of power to fly with safety.

Take-off Power

As mentioned under " Carburation," additional power beyond normal maximum ground power can be obtained for a short period during take-off if extra-rich mixture is provided. As the boost control is limiting the carburetter throttle opening, some means must be provided to force the boost control to give a slightly larger throttle opening, and is known as over-riding the boost control. In view of the increased compression and expansion pressures as well as cylinder temperatures, it is imperative that from 10 to 15 per cent. increase in mixture strength is given (average 12 per cent.) to prevent detonation and provide some form of internal cooling for the cylinder. In the Hobson scheme the boost over-ride and the enrichment jet are interlocked so that one cannot be used without

the other, the enrichment jet coming into action slightly earlier than the over-ride action.

There are two ways of obtaining boost over-ride: (1) mechanical method, and (2) airleak method. The mechanical over-ride consists of a fork-ended lever which, when moved, pushes the whole capsule assembly in the boost control away from the adjustment end. The amount of movement can be altered by an adjustment and this is locked to prevent variation of boost pressure when the control lever is moved to the over-ride position. Movement of the capsule means movement of the control valve, and as the ports are uncovered, oil flows and moves the piston. This, in turn, through the linkage, opens the carburetter throttle and the boost pressure rises. The increase in boost pressure is communicated to the capsule chamber, compresses the capsule and draws back the valve to shut off the oil supply. This means that the boost control settles down to control at a higher boost pressure and therefore, power output, during which the enrichment valve is supplying the ne extra fuel. The increased power, especially if used in conjunction with a constant speed or controllable-pitch airscrew, is of the greatest help in getting off the ground in the shortest possible time and assisting in a rapid climb. When safely clear of any possible obstacles, the over-ride may be put out of action and the aeroplane allowed to climb on normal full power.

The "air-leak" over-ride is a method whereby a larger throttle opening is obtained on the ground for take-off purposes by allowing some of the pressure to leak from the boost control capsule chamber at a steady and accurately controlled rate. In addition to the pipe connecting the capsule chamber to the *pressure* side of the blower is another pipe connected to the *suction* side. Normally, this latter pipe is closed by a valve called the over-ride valve. The inlet pipe elbow on the capsule chamber has a small jet of the "plate" type and is known as a sharp-edged orifice, and the outlet pipe has a venturi, this combination of orifices having been found to be least affected by external influences such as temperature, etc. This is shown in Fig. 11. Fig. 12 shows normal and take-off H.P. curves.

By carefully regulating the relative size of the sharp-edged orifice and the venturi, an exact drop in pressure in the capsule chamber can be repeatedly obtained each time the over-ride valve is opened. This drop in pressure causes the capsule to expand, which in turn pushes the control valve in the same direction as with the mechanical type of over-ride, thereby giving a definite increase in throttle opening.

Calibration of Venturi

When once the correct size of the throat in the venturi has been found it is "flowed" on a jet-calibrating machine, and its flow in cubic centimetres per minute recorded so that all further supplies for that particular

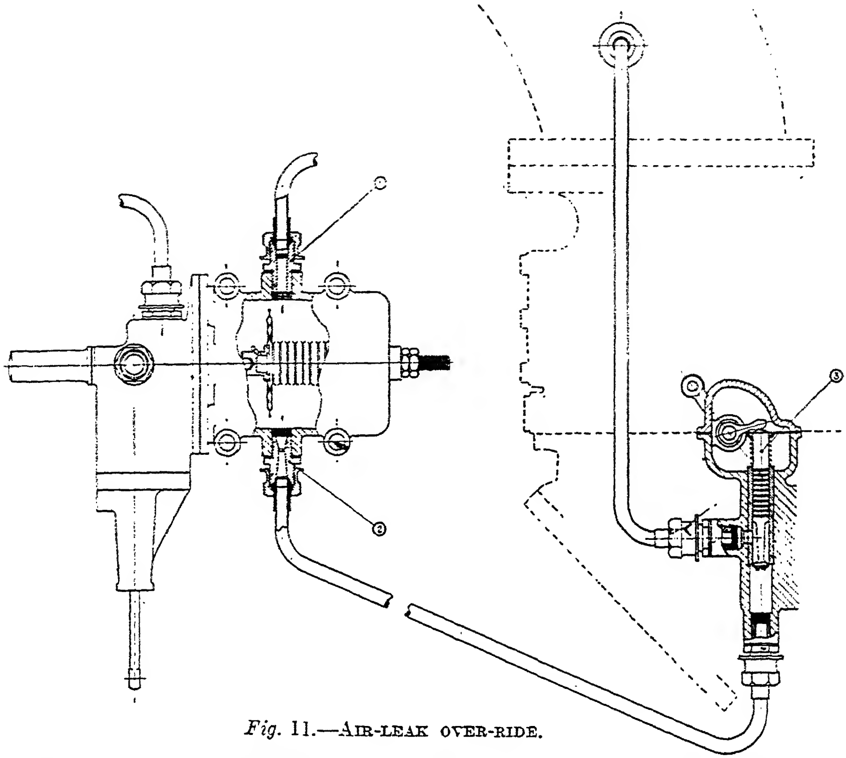


Fig. 11.—AIR-LEAK OVER-RIDE.

combination of carburetter and engine can be accurately repeated. The sharp-edged orifice is carefully drilled. If on opening the over-ride valve the boost pressure increase is insufficient, it is a sign that the orifice is too large, while on the other hand, if the pressure rises too high, it will be necessary to open up the hole until the required drop across the capsule chamber is obtained. This alteration in size should be done with a jet reamer, a very little at a time, as a small alteration in size gives quite an appreciable change in boost pressure. It is essential that the sharp-edged orifice is the controlling factor on the pressure side, and this is why too small a pipe, with its internal friction, can cause surging. The over-ride valve and the enrichment valve are to-day invariably built into the carburetter and are operated by two cams fixed on a common shaft. By arranging the enrichment cam to start opening its valve a few degrees before the over-ride valve starts to open, fuel reaches the engine before the boost pressure goes up and momentary detonation is thereby avoided.

Every Hobson boost control has a mark number to identify it, as the general shape and working conditions vary with each make and

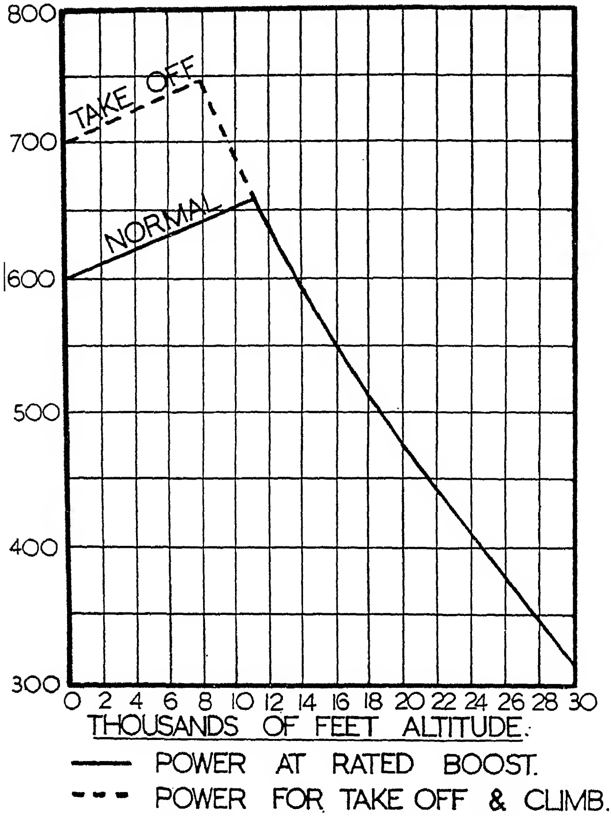


Fig. 12.—NORMAL AND TAKE-OFF H.P. CURVES.

type of engine. Working oil temperatures and pressures vary as well as the amount of over-ride, so each separate t[illegible] of boost cont[illegible] has its own t[illegible] schedule, giv[illegible] the following [illegible]tails with whic[illegible] each control mu[illegible] comply :—

(1) Size of leak hole in piston ($\frac{3}{4}$–$1\frac{1}{2}$ mm.).
(2) Working oil pressure (varies b[illegible]tween 40 [illegible] 90 lbs. per square inch).
(3) Working o[illegible] temperature (varies between 70 and 90° C.).
(4) Oil flow with valve central, *i.e.*, both ports closed. This shows permissible leakage past valve.
(5) Oil flow with valve 0·060 in. on either side of central position.
(6) Length of piston stop if not adjustable.
(7) Calibration of venturi in cubic centimetres.
(8) Change of pressure in capsule chamber required to make piston move from one end of cylinder to the other. Regulations call for a change of not more than $\frac{1}{8}$ lb. per square inch, except in isolated cases.

Fig. 13 shows a boost control test rig. The control is fixed firmly in position and connected up to a source of hot-oil supply at the correct pressure. Against the end of the valve is fixed a clock gauge reading in 0·001 in., and in the background will be seen the oil tank fitted with an electrical immersion type heater. Above the tank is a distant-reading thermometer; on the right is an oil pressure gauge and a mercury gauge

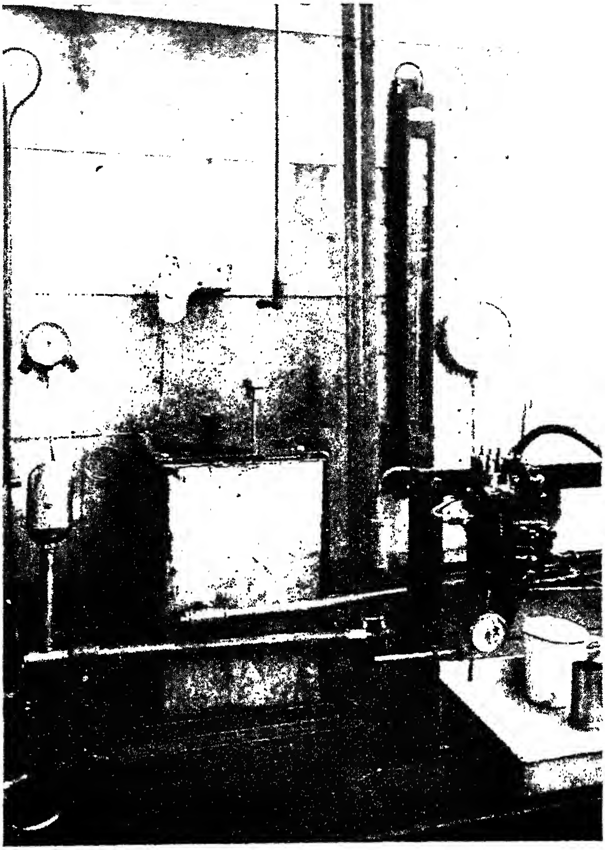


Fig. 13.—BOOST CONTROL TEST RIG.

for reading the capsule chamber pressure. The boost control must be sufficiently sensitive that a maximum ·e movement of)2 in. either side ıe centre position .ld cause the .on to travel from ɔ end to the other. ɔ amount of oil .ssed in a given time is checked with a stop watch and a measure to ensure that it comes within the limits set out in the test schedule for particular type.

The fit of the ılve in the body ·important. After several manufacturing processes it is ground to very fine limits and then lapped into the body. When lightly lubricated it should just slide through by its own weight (see Fig. 14). The greatest care must be taken in handling these valves to avoid damage, and when assembling the boost control every part must be scrupulously clean. Union nuts and orifices must be blanked off until the control is required and after lightly oiling all steel parts the control should be well wrapped in grease-proof paper and kept in a dry place. The capsules are made of specially tempered steel. Exactly the right amount of air is left inside them before sealing to compensate for temperature changes and on no account should any other type be fitted or trouble will occur through fatigue and fracture of the metal as well as incorrect and insensitive control of boost pressure.

Boost-Control Linkage

There are two main types of linkage, one in which there are hinged

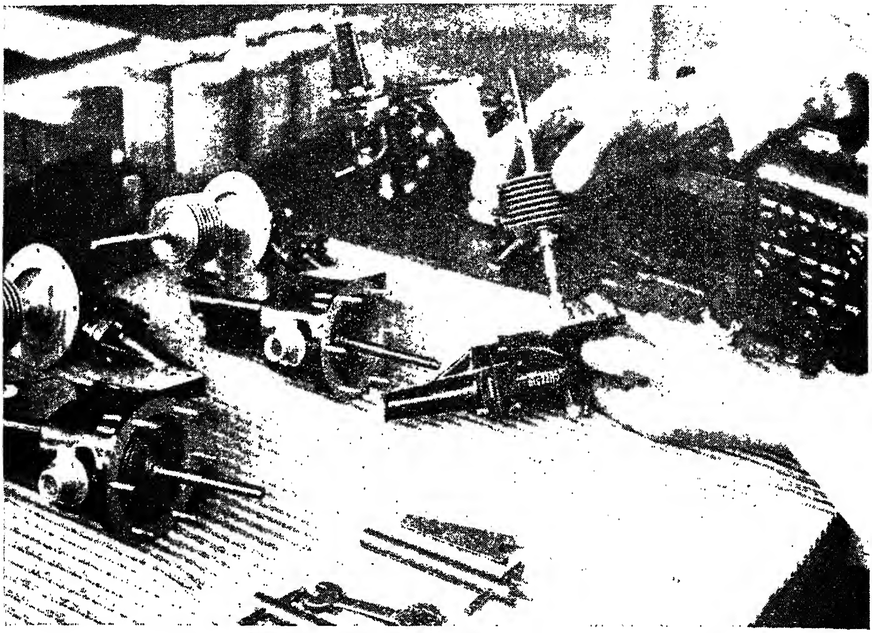


Fig. 14.—CHECKING THE FIT OF A BOOST CONTROL VALVE.

links between the carburetter throttle lever and the pilot's throttle lever, the length of which is altered by the boost control as in Fig. 3. The other consists of a swinging fulcrum. The connection between the pilot's lever and the carburetter throttle pivots on the fulcrum pin, whilst the boost control shifts the position of the fulcrum pin. The design of both call for considerable experience and with the former it is essential that the links go to their least bent position under slow-running conditions.

In a few isolated cases the necessary oil pressure drops so low at tick-over speed that it is insufficient to support the piston. The result is that when the pilot's lever is moved towards the "open" position, instead of the carburetter throttle being opened, the piston is forced towards the "ground" position until it reaches the stop, when the throttle opens more or less suddenly and the engine speeds up more rapidly than desirable. In such cases the piston is assisted to remain in the slow-running (altitude) position by a spring which may be attached externally or fitted inside the servo piston cylinder. The exact strength must be carefully chosen, as if too strong, excessive boost pressures will be the result and the piston may be sluggish in operation in one direction.

Boost Pressure and Mixture Strength

In the Hobson Master-Control Scheme different boost pressures are correlated with their appropriate mixture strengths, but as the mixture

strength is automatically controlled from sea-level to the ceiling of the aeroplane the scheme will be easier to understand if automatic mixture controls are dealt with first.

Ever since aeroplanes were able to fly at altitudes where it was necessary for the mixture strength to be weakened, innumerable efforts have been made to construct devices that would by automatically giving the correct mixture strength at any altitude, take away from the pilot the irksome duty of watching an altimeter and moving a mixture lever to its correct setting. Tapered needles controlling fuel flow through orifices have proved to be unsatisfactory. Putting suction in the space above the fuel in the float chamber will control mixture strength, but is affected by varying throttle openings. The primary condition for an automatic mixture control is that it shall be affected by altitude only and not by anything else. In addition, the shape of the throttle curve given by the carburetter is important and to obtain the most efficient results with any automatic mixture control it is essential that the mixture control valve of the carburetter gives equal and progressive changes in mixture strength with equal and progressive movements of the mixture control lever. If changes occur in mixture strength for any given setting of the mixture lever, due to alteration of throttle opening or the speed of the aeroplane, then the adaption of an automatic mixture control is not efficient.

Modern aeroplane carburetters require a mixture control capable of weakening the mixture strength by at least 40 per cent., and it is only too obvious that with a range of mixture strength as generous as this, it can be abused either by carelessness, inexperience or distraction of the pilot's attention. On the one hand, excessive use of the mixture control can cause damage to the engine through overheating from mixtures being too weak, and on the other hand, wastage of fuel will reduce the anticipated range of the aeroplane. Many attempts on long distance records have failed through the incorrect use or abuse of the mixture control.

After many years of experimenting, a device known as the Hobson-Penn Automatic Mixture Control was patented, which was based on a principle quite different to all previous methods and which took advantage of the following discovery. It is a well-known fact that as mixture strengths are weakened to the point where maximum power is obtained with minimum fuel consumption—known as W.M.M.P.—engine temperatures rise to a dangerously high point, and carburetter settings are always fixed at a mixture strength sufficiently richer than this point to be safe, usually about 10 per cent.

It was found, however, that if mixture strengths considerably weaker than that known as W.M.M.P. were used, temperatures fell if the mixture was made weak enough to cause also a fall in engine revolutions. This drop in revolutions was found to be best limited to about 3 per cent.; if taken too low the engine became unsteady.

A Typical Curve

A typical curve is seen in Fig. 15, in which " C " shows the relative mixture strength and temperature known as W.M.M.P., a condition that must always be avoided when flying. " B " shows the normal safe mixture for full power conditions approximately 10 per cent. richer than W.M.M.P., while " A " shows the over-rich mixture necessary for take-off conditions. " D " shows the cruising mixture strength giving a drop in revolutions with steady running and safe temperatures.

The Hobson-Penn Automatic Mixture-Control

The Hobson-Penn Automatic Mixture-Control has two distinct settings, one for maximum power and manœuvrability, known as normal—" Rich Automatic "—and the other for maximum economy with reduced engine revolutions known as " Weak Automatic." " Rich Automatic " corresponds to the condition shown at " B " on Fig. 15, and " Weak Automatic " to the condition " D," it being impossible to run the engine with a mixture strength and temperature as at " C." At the same time the mixture is automatically corrected for altitude, not merely to the engine's rated height, but to the aeroplane's ceiling. Prolonged tests have shown that when properly installed this device will, on an average, increase the cruising range by 20 per cent. over that obtained by the average pilot.

The advantage of such a device in the hands of unskilled pilots is obvious, as a difference of as much as 50 per cent. in fuel consumption is frequently recorded between aeroplanes of the same type when flown by different pilots under identical conditions.

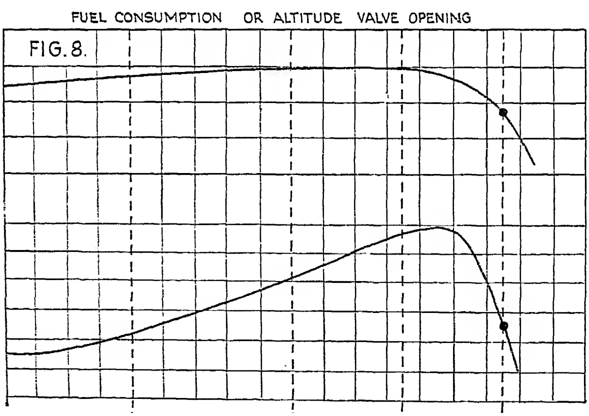


Fig. 15.—CURVES OF MIXTURE STRENGTHS AND CYLINDER TEMPERATURES.

(C) weakest mixture for maintaining power; (B) normal power mixture (" Rich Automatic "); (D) cruising mixture strength, giving drop in revs. with safe drop in temperature and steady running (" Weak Automatic "); (A) twelve per cent. richer than (B) for take-off boost.

Fig. 16 shows the construction of the Hobson-Penn Automatic Mixture Control. It contains a barometric bellows, a piston valve and servo-piston mechanism somewhat like the Hobson boost control, but differing as follows. The capsule chamber is open to atmos-

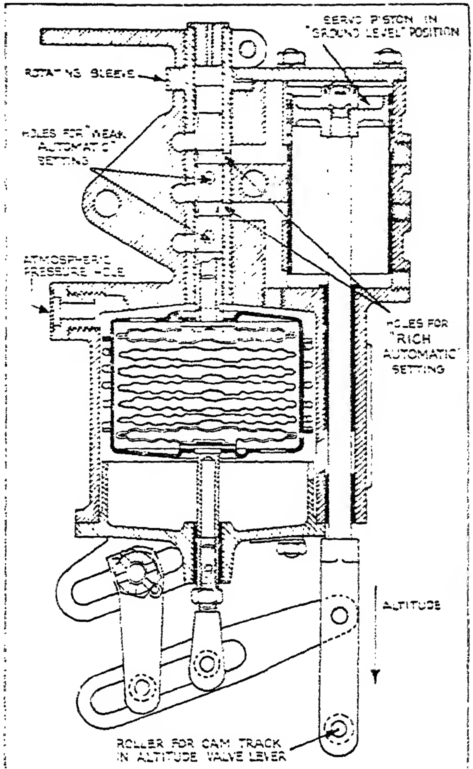


Fig. 16.—Section of Hobson-Penn Automatic Mixture Control.

phere, and one end of the capsule is so arranged that a change of air pressure causes a small movement of the servo piston and not a complete one as in the boost control. Surrounding the piston valve is a rotatable sleeve having two sets of holes at different heights. When the sleeve is turned in one direction the upper holes become the oil controlling ports. If the sleeve is turned through 90 degrees these ports become inoperative, and the two lower ones come into action, and as for any constant altitude the servo piston always moves to a position where it closes off the oil supply to both sides of the piston, changing from one set of holes to the other will cause a jump in the piston movement depending on how far apart the holes are. As the servo piston is coupled to the altitude valve of the carburetter, it is obvious that near the ground the piston, as shown in Fig. 16, will be at the top of its stroke if the sleeve is in the "Rich Automatic" position. On the sleeve being turned to the "Weak Automatic" position the piston near ground level will immediately move to some other position lower down, thereby giving a weaker mixture. The exact amount of movement to produce the required drop in revolutions and temperature cannot be accurately calculated, and flight tests at various heights and engine speeds are necessary to determine the required characteristics of both engine and carburetter. Once found for any particular combinations of engine and carburetter, the necessary linkage, etc., can be reproduced with great accuracy. The distance between the holes in the sleeve depends on the difference in mixture strengths required to give the necessary drop in revolutions from the power setting to the economy setting. This varies with different types of engine and the sleeves are standardised with about five different spacings for the holes, and are known as "A," "B," "C," "D" and "E" sleeves, an "A" sleeve giving the

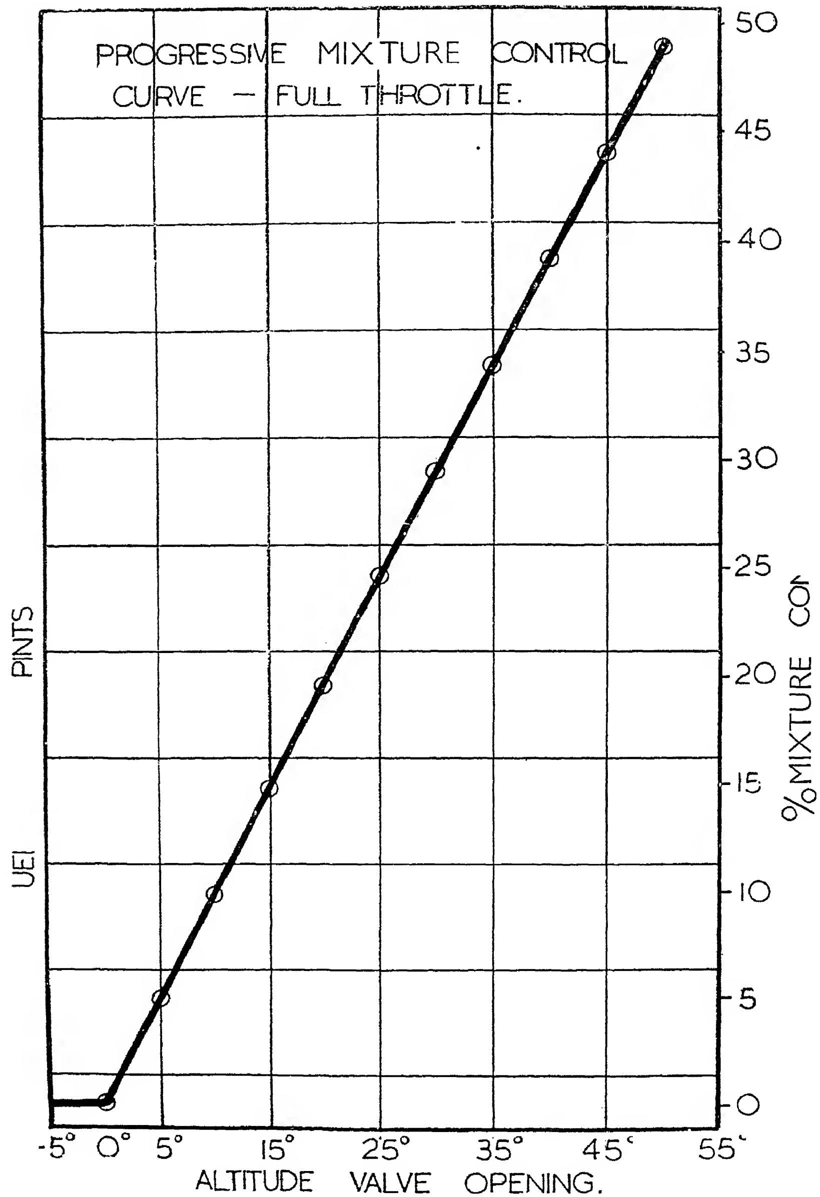


Fig. 17.—A TYPICAL MIXTURE CONTROL CURVE OF A CLAUDEL-HOBSON AIRCRAFT CARBURETTER.

It will be noticed that there is a 5° overlap of the valve in the closed (Rich) position.

smallest piston movement on change-over and an "E" sleeve the greatest. Fig. 17 shows a correct mixture control curve taken on a carburetter during a "blower" test, which test will be described later. Fig. 18 shows a W.M.M.P. curve, also the normal throttle curve (Rich Automatic), as well as the Weak Automatic curve; they must all be parallel throughout the cruising range. If the mixture control curve of the carburetter is not a straight line and is affected by varying throttle openings, the cruising portion of the throttle curve will vary in shape at different heights and speeds. Any variation from a strictly horizontal position will mean incorrect mixture strengths, possibly too weak in places, but mainly too rich and therefore wasteful.

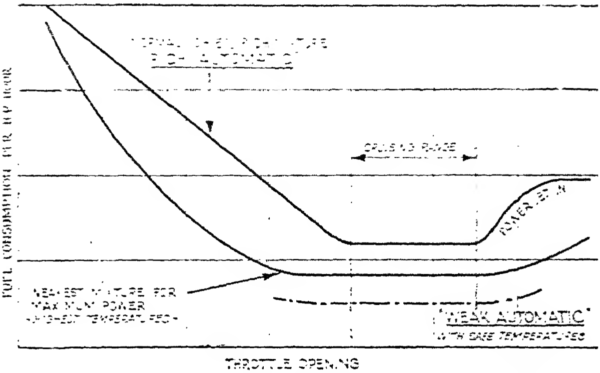


Fig. 18.—"RICH AUTOMATIC," W.M.M.P. AND "WEAK AUTOMATIC" CURVES.

On more than one occasion automatic mixture controls of the *single-stage* type have failed through puncture of the bellows, this causing the mixture to go to "altitude" conditions with the result that, as the aeroplane descended, the engine stopped owing to weakness, and the pilot had to make a "dead" landing. The capsules were therefore spring-loaded so that in case of breakage the control went to the "ground rich" position. This meant that there was no automatic control of mixture strength and the aeroplane's cruising range was badly reduced, as the pilot was compelled to fly on unnecessarily rich mixtures. With the Hobson-Penn device this cannot happen for two reasons. The barometric portion of this instrument is not a plain bellows of the concertina type, but a nest of seven separate capsules held in a spring-loaded casing which, while allowing the capsules to expand and contract, keeps them in contact. Failure of one capsule means only a small alteration in mixture strength and even if more than one went out of action, the pilot can always move his control to the "Rich Automatic" setting and obtain a safe mixture without losing much of his cruising range. The second safety device comes into action if through the presence of dirt in the oil, the valve sticks inside the sleeve. Should this happen, the piston moves until the spring surrounding the capsule chamber becomes coil-bound, after which the full pressure of the piston is placed on the valve and so frees it. The piston then returns to the setting correct for the

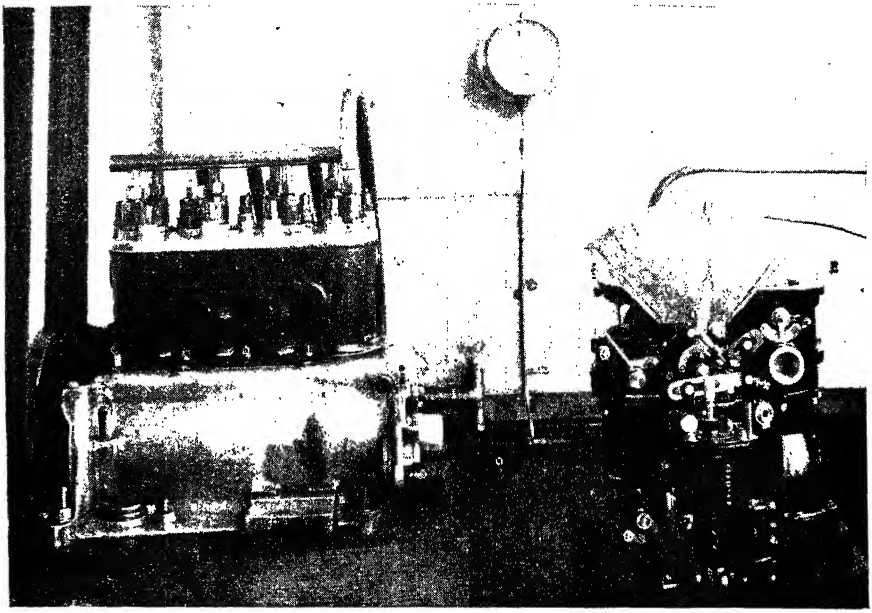


Fig. 19.—TESTING THE AUTOMATIC MIXTURE CONTROL ON A CARBURETTER.

On the left is a vacuum pump. The carburetter is fitted with a dial and a pointer to register the movement of the Automatic Mixture Control at various altitudes.

altitude at which it happens to be. The testing apparatus is seen in Figs. 19 and 20.

Three-phase Boost Controls

It has already been demonstrated how power output is intimately linked up with mixture strength, three different mixture strengths being desirable, viz., (i) cruising mixture (weak for maximum economy), (ii) normal rich for rated boost conditions, and (iii) over-rich for take-off conditions.

To reduce the number of responsibilities placed on the pilot, the Hobson Three-phase Boost Control was devised, and with this each range of boost pressure is automatically given its most suitable mixture strength. It was therefore arranged that, while keeping the variable datum action to ensure smooth control of engine power, the whole capsule assembly should be given, not merely one definite displacement as previously explained with regard to mechanical over-ride, but three definite displacements. In effect, this means three distinct ranges of boost pressure.

It was arranged that by means of three separate cams of varying lifts, the capsule assembly could be given three different settings or "datum lines" from which to start controlling the boost pressure. By means of adjusting screws the movement given by each cam could be regulated

and individual adjustment of each stage of boost pressure maintained to the desired figure.

It will be recalled that the Hobson-Penn Automatic Mixture Control has only two main mixture settings under the control of the pilot, "Rich Automatic" and "Weak Automatic," and by coupling up the three cams to the lever giving this change over in mixture strength, it was possible to arrange that (i) during the cruising boost range, the automatic mixture control was in the "Weak Automatic" setting; (ii) during the normal boost range, it was in the "Rich Automatic" setting; and (iii) during the take-off boost range it remained in the "Rich Automatic" setting, thereby ensuring that power could not be obtained on mixtures too weak to be safe.

A further provision was made in the carburetter, in that when in the Cruising-Boost Weak Automatic setting, the power jet was cut out of action for the following reason. Reference to Figs. 4 and 12 will show that after an aeroplane has passed the engine's rated height, power output falls steadily, and under these conditions reduced power is always accompanied by a drop in temperature. When the aeroplane is 3,000 or 4,000 ft. or more above the engine's rated height, it is safe to open the throttle wide on a cruising mixture strength. However, as the power jet is timed to come into action before the pilot's throttle lever approaches the full

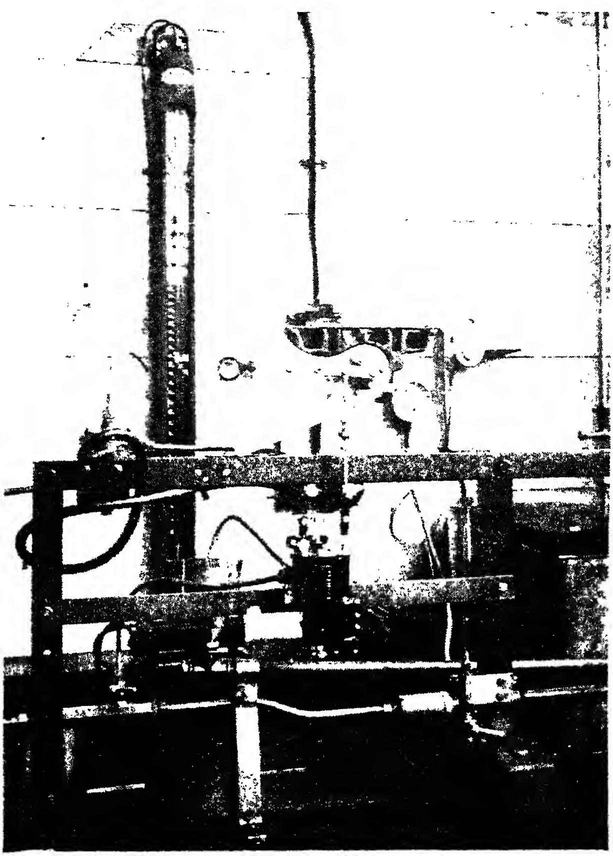


Fig. 20.—Testing a Hobson-Penn Automatic Mixture Control Unit.

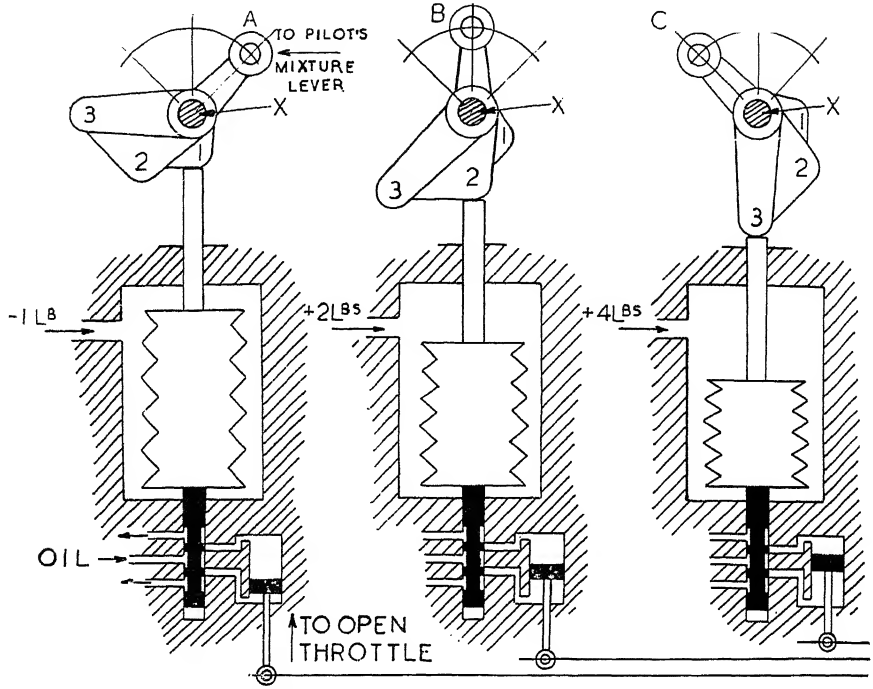


Fig. 21.—A THREE-PHASE BOOST CONTROL SHOWN DIAGRAMMATICALLY WITHOUT VARIABLE DATUM ACTION.

open position, this cannot normally be done. For long-range aeroplanes flying at altitudes well above their rated height, fuel would be normally consumed *viâ* the power jet under conditions when it was not needed, thereby reducing the payload and range of the aeroplane. By automatically cutting out the power jet action whenever cruising conditions appertain, the range of the aeroplane will be extended. This is particularly important with large bombing types which must carry the calculated minimum safe weight of fuel for the journey and which in war-time may do their return journey without their bomb load under conditions which compel them to fly as fast as possible at considerable heights. It is obvious that under these conditions and using the above scheme either a larger bomb load for a given journey can be carried or alternatively for the same load, a greater range is available, due solely to the better fuel consumption.

Fig. 21 shows diagrammatically a three-phase boost control in which the three cams are operated by the mixture lever. The mixture lever in the pilot's cockpit will therefore have three fixed settings, viz., "cruising," "normal" and "take-off," he only having to select the appropriate setting according to his requirements, the automatic mixture control

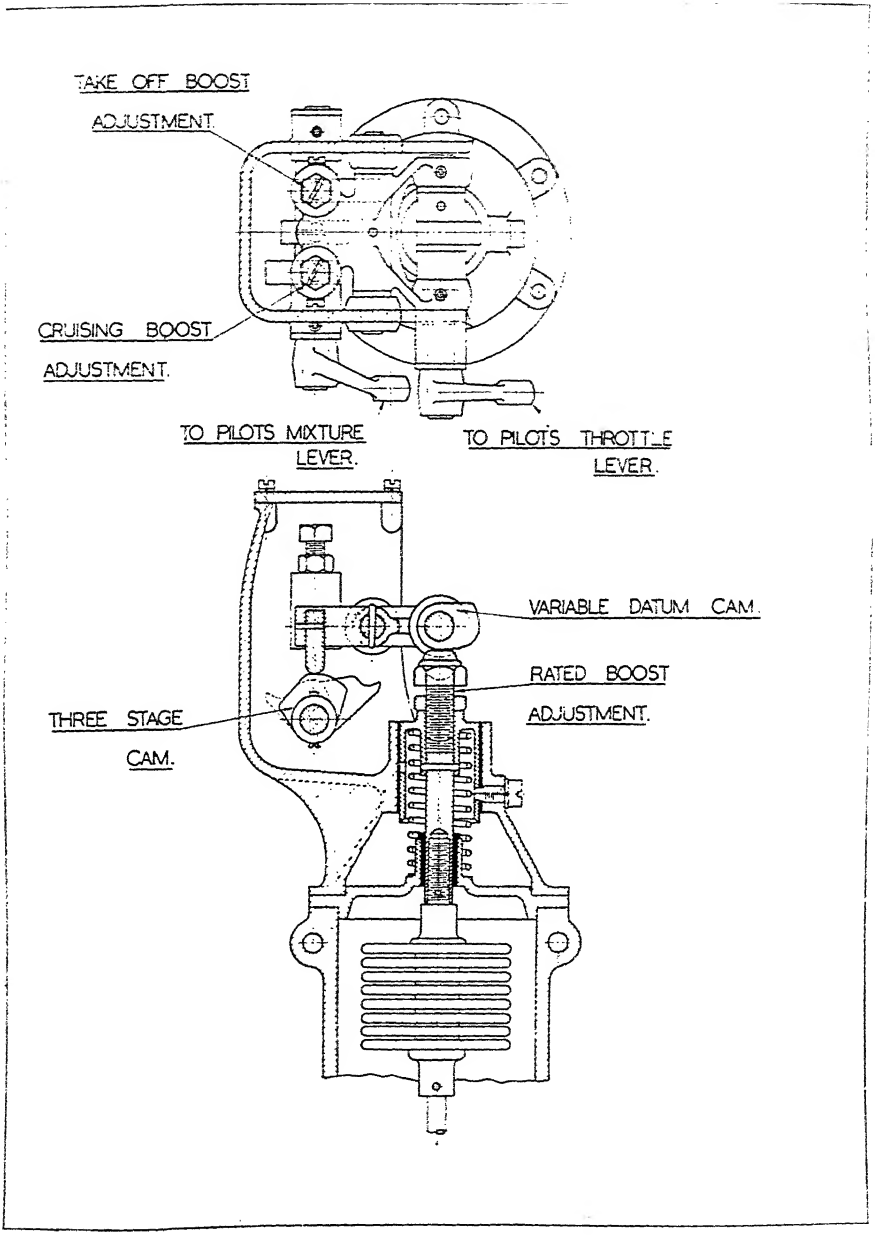


Fig. 22.—Three-phase boost control with variable datum cam shown diagrammatically.

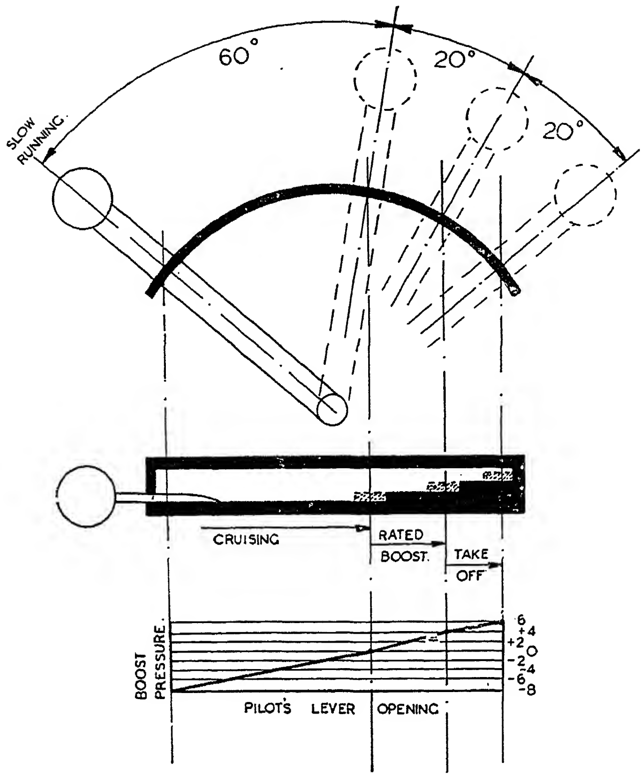


Fig. 23.—THREE-PHASE BOOST CONTROL, PILOT'S LEVER MOVEMENT AND BOOST PRESSURE CURVE.

keeping the mixture strength correct at any altitude on any of the three settings, while with all three settings a variable datum action is obtained by the variable datum cam operated by the *pilot's throttle lever.* See Fig. 22. While possessing many outstanding advantages, this scheme was open to criticism on the score that moving from one cam to another would, for a given set position of the pilot's throttle lever, give a rather sudden jump in boost pressure that would require simultaneous manipulation of the throttle lever to modify, and an improved version of this scheme is known as "The Single Power-Lever Three-phase Boost Control." In this the pilot's mixture lever has only two mixture settings, Rich and Weak, controlling only the "Rich Automatic" and "Weak Automatic" setting of the Hobson-Penn Automatic Mixture Control. The separate variable datum cam on top of the boost control capsule assembly is done away with and the "cruising cam" of the three used, has its contour extended and shaped to give a variable datum action as the throttle lever is moved from the slow running position to the maximum cruising speed position, the cams being turned by the *pilot's throttle lever* and *not* by his mixture lever. This range of movement is accompanied by a setting of the mixture lever in the Weak (Automatic) position. The next range of throttle lever movement is relatively small compared with the first and is up to the normal rated boost position. During this movement the mixture lever must be in the Rich (Automatic) setting and the power jet also comes in. The third range of movement, which is also relatively small, is to the

take-off position, and here again the mixture lever must remain in the Rich position, the enrichment jet in the carburetter being used in the customary fashion.

The pilot's cockpit control must therefore have two positions for the mixture lever and three for the throttle lever, and Fig. 23 shows the sort of gate necessary. Fig. 23 also shows the type of boost pressure curve obtained with this scheme when compared with the pilot's lever movement, the boost pressure figures and angular movement, of course, being comparative only, the difference depending on the design of the engine.

A summary of the advantages given by this scheme so far are as follows :—

1. The pilot cannot give his engine boost pressures in excess of those set by the various adjustments.
2. He has a smooth and progressive control of engine power similar to an unsupercharged engine and has no lost motion in the throttle lever below rated height.
3. He cannot run on mixture strengths which, allowing for the power being developed, will be either too weak or wasteful.
4. He need not alter his mixture lever for changes in altitude or throttle opening.

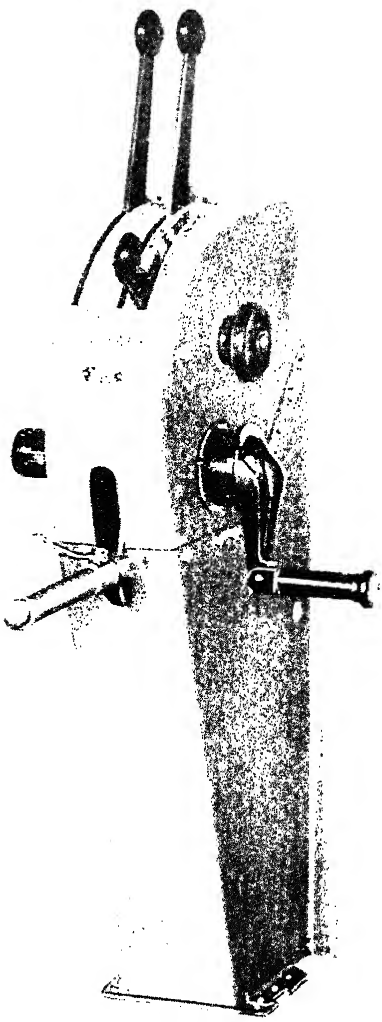


Fig. 24.—A HOBSON TWO-ENGINE COCKPIT CONTROL WITH ONLY ONE MIXTURE LEVER FOR BOTH ENGINES, WHICH ARE BOTH FITTED WITH AUTOMATIC MIXTURE CONTROL AND VARIABLE DATUM BOOST CONTROL.

A parking brake and tail trimming device is incorporated.

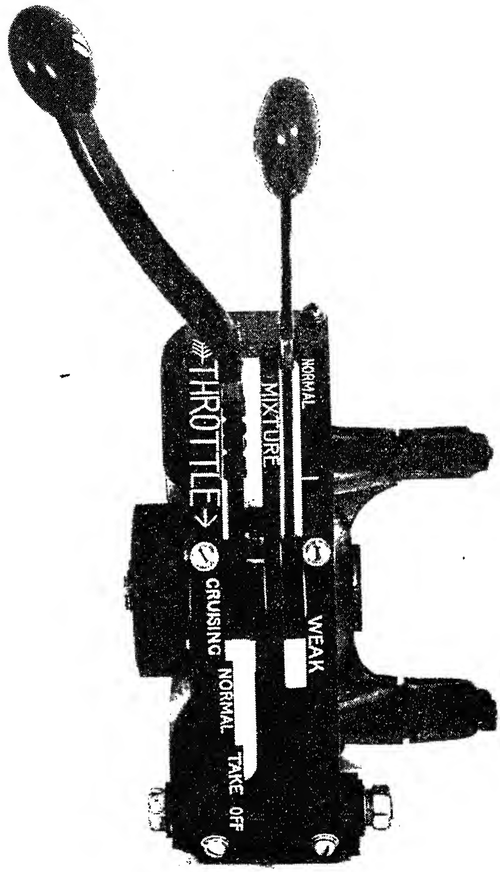


Fig. 25.—A HOBSON COCKPIT CONTROL FOR A SINGLE ENGINE AEROPLANE FITTED WITH A "SINGLE POWER LEVER MASTER CONTROL CARBURETTER." Refer also to Fig. 23.

5. He need not try to estimate correct mixture strength by watching the thermometer, boost pressure gauge and altimeter, as is the method employed in some countries.

It will be seen, therefore, that the pilot's duties have been vastly relieved, there remaining one possible mistake by the pilot when choosing the position of his mixture lever. It is possible so far—if the pilot's attention is distracted or he is forgetful or inexperienced — for him to move his throttle lever to the normal boost and take-off boost position and leave his mixture lever in the weak setting, thereby endangering the engine. To prevent this the Hobson Pilot's Cockpit Control was patented, and is made in a variety of shapes and types, each designed to suit some particular aeroplane. In this, by means of internal mechanism, the pilot's mixture and throttle levers are so interlocked as to eliminate all possibility of such a mistake on his part.

If the pilot leaves the mixture lever in the weak automatic setting and pushes his throttle lever anywhere past the maximum cruising position, it automatically moves the mixture lever back to the rich setting. Similarly, if when cruising with the weak mixture setting, the pilot closes his throttle to land, the mixture lever is again pushed to the rich setting, thereby avoiding the risk of the engine suddenly stopping through weak mixture. It is unlikely that the engine would stop if allowed to tick over

as the mixture control does not affect slow running mixture, but if, as is often the case, the pilot opens up his engine for a second or two when approaching the ground, there is always the danger of the engine stalling on a weak setting and the pilot is faced with the risk of landing with a "dead" engine.

Figs. 24, 25 and 26 show various types of Hobson Cockpit Controls. Fig. 24 shows a two-engine control in which either engine can be opened up separately, and only one mixture lever for two engines. It is one of the earlier type for carburetters having two-stage automatic mixture control and a variable datum boost control, but not of the three-stage type. The mixture lever, therefore, has three settings, take-off, normal rich and weak cruising. In addition there is a sealed gate beyond full throttle position, which gives in case of dire necessity below rated height, a higher boost pressure than take-off boost, by mechanically opening the throttle beyond that equivalent to the take-off setting. As this may seriously strain the engine, and any damage—if done—may not become noticeable for some time after, a thin wire crosses the gate opening, which wire is sealed. It is not possible to use this emergency setting without breaking the wire and there is therefore a permanent record when the aeroplane lands that the engine has possibly been strained and needs a thorough inspection before being given further use.

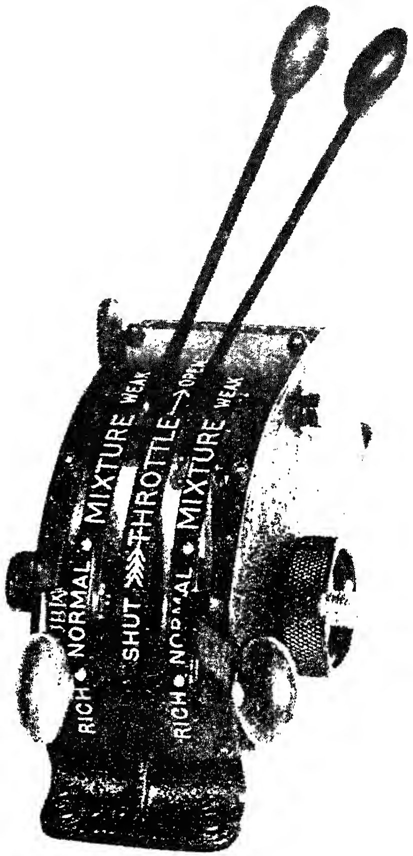


Fig. 26.—A HOBSON TWO-ENGINE COCKPIT CONTROL FOR ENGINES NOT FITTED WITH AUTOMATIC MIXTURE CONTROL.

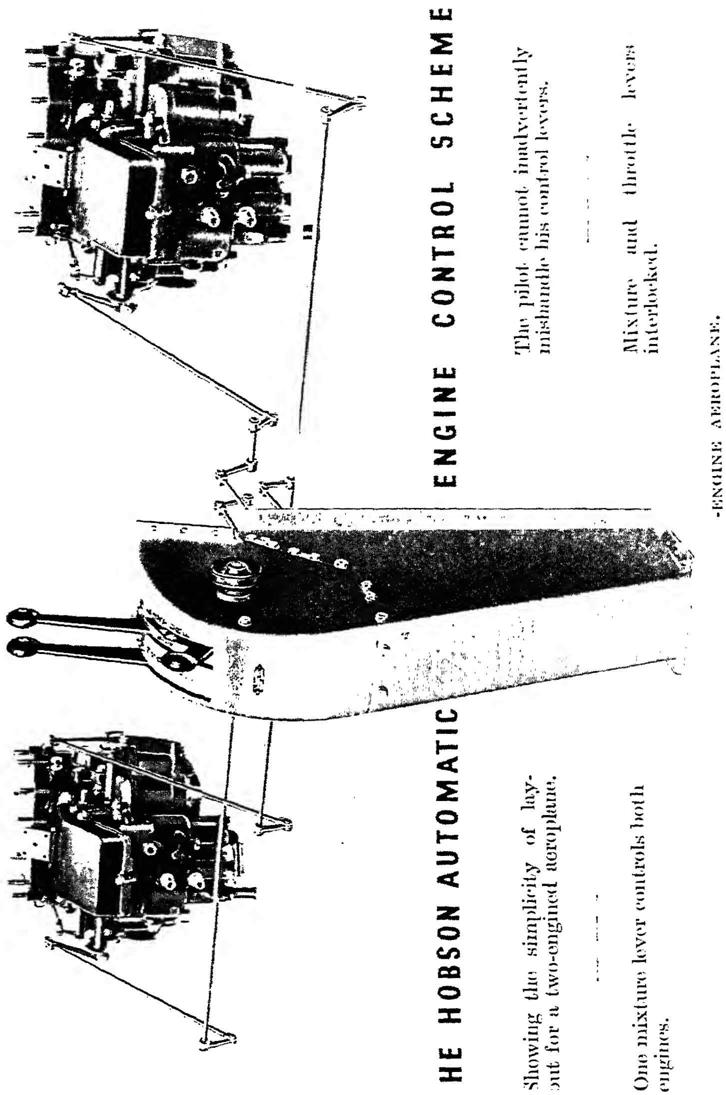
Fig. 25 shows a cockpit control for a carburetter of the single-power lever type, while Fig. 26 shows a control for a two-engine aeroplane fitted with variable datum boost controls, but *not* automatic mixture control, the mixture having to be adjusted by hand according to altitude at the

Fig. 27.—ONE OF THE ASSEMBLY BENCHES FOR HOBSON PILOT'S COCKPIT CONTROLS.

discretion of the pilot. The mixture and throttle levers are, however, interlocked to the extent that neither throttle can be closed without pulling the mixture lever back to the normal position. If the mixture levers are pulled back to the position marked Rich, interlinkage in the carburetters give override and take-off mixture, thereby avoiding the necessity of an additional lever. Fig. 27 shows cockpit controls being assembled.

Automatic Correction of Any Error in Handling Mixture and Throttle Levers

It will be seen that a complete scheme has been devised wherein the engine is protected from incorrect boost pressures and mixture strengths under every condition of flight, and that any error in handling the mixture and throttle levers by the pilot is automatically corrected. In air warfare and aerobatics, when it is impossible—with ordinary methods and the complicated array of levers and instruments—for the pilot to pay the necessary attention to correct mixture strengths and boost pressures, the underlying feeling that he cannot make a mistake that might " let him down," is one of immense psychological value. Fig. 28 shows a typical layout for a two engine aeroplane as now fitted with the Hobson Master Control Scheme, which is the subject of numerous British and Foreign Patents, and Figs. 29, 30 and 31 show various types and sizes of Hobson Master Control Carburetters.



CONSTANT SPEED AIRSCREWS

When a constant speed airscrew is fitted to an engine, the control of the mixture strength becomes extremely difficult. The normal method of checking the approximate mixture strength is as follows :—

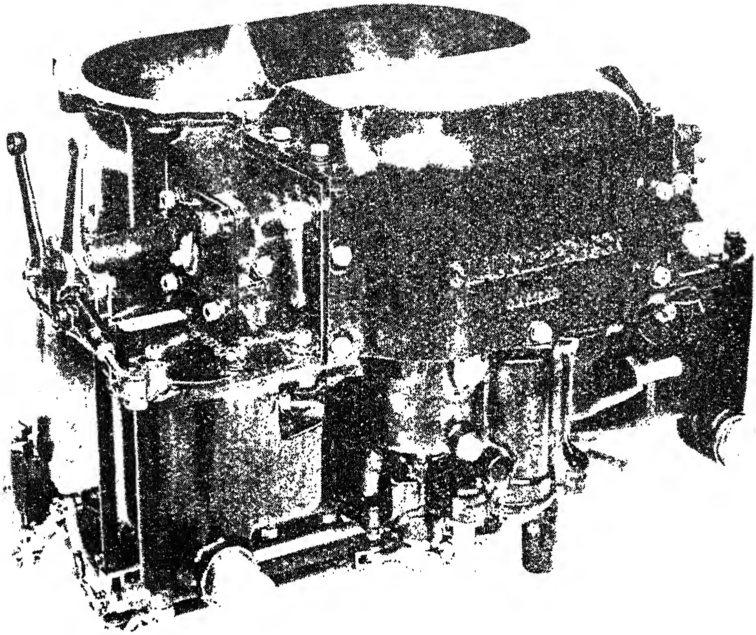


Fig. 29.—A HOBSON MASTER CONTROL CARBURETTER, INVERTED TYPE, TWIN BARREL.

The pilot opens his mixture lever slowly, until he gets a drop in engine revs. of 3 per cent. He keeps his mixture lever at this setting and opens the throttle until the 3 per cent. drop in revs. is restored. This gives him a mixture strength as near to the economical position as is safe.

It is obvious that with an airscrew which changes its pitch automatically whenever anything happens which alters the load or speed of the engine to which it is fitted, this method of checking the mixture strength becomes useless, for as the pilot weakens the mixture and causes a drop in engine revs., the airscrew will automatically go to a finer pitch and restore them again.

The only reliable method of controlling the mixture strength is by a completely automatic device and this has brought into prominence such automatic mixture devices as the HOBSON-PENN.

CONTROLLABLE PITCH AIRSCREWS

Where controllable pitch airscrews are installed, *i.e.*, those having two or three fixed settings under the control of the pilot, a two-stage mixture control such as the HOBSON-PENN again has many advantages.

When, as previously explained, there are three positions of the pilot's mixture lever, namely, "take-off," "rich automatic" and "weak

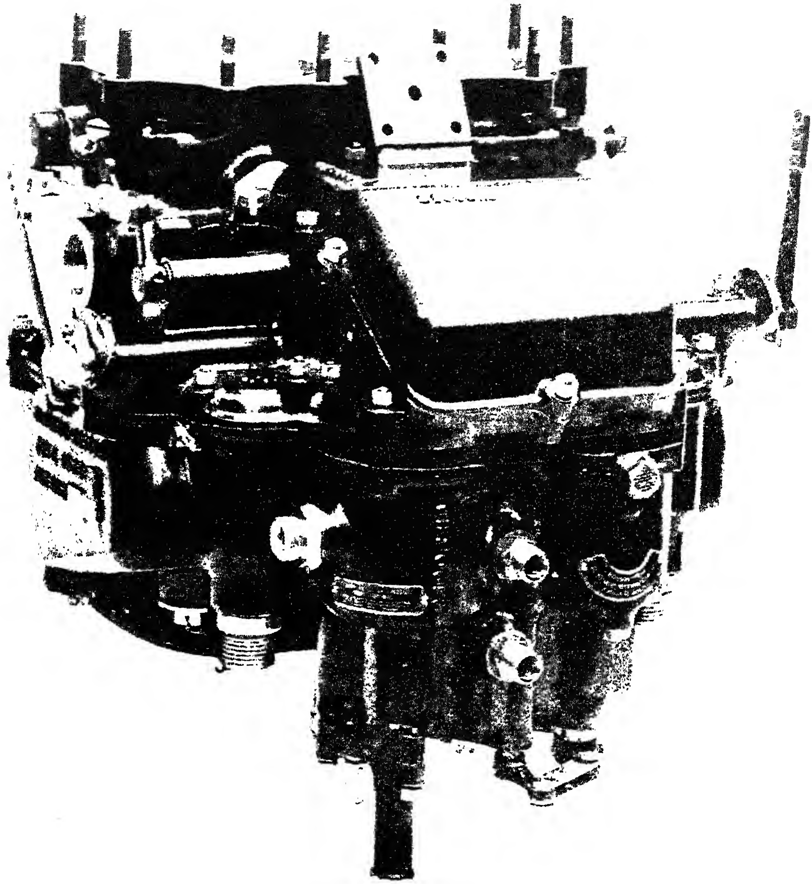


Fig. 30.—A MASTER CONTROL CARBURETTER, TWIN VERTICAL TYPE.

automatic," this lever can be connected to the control by means of the controllable pitch airscrew, so that in the "take-off" position, where extra boost is given, accompanied by an extra rich mixture, the airscrew is set to its finest pitch, thereby allowing the engine to develop its maximum power.

Again, when the mixture lever is moved to the "rich automatic" position for maximum power and manœuvrability, an intermediate setting of the blades can be given.

Lastly, for economical cruising, when the mixture lever goes to the "weak automatic" position, the airscrew can be given its maximum pitch. In this way the utmost efficiency is ensured, both from the point

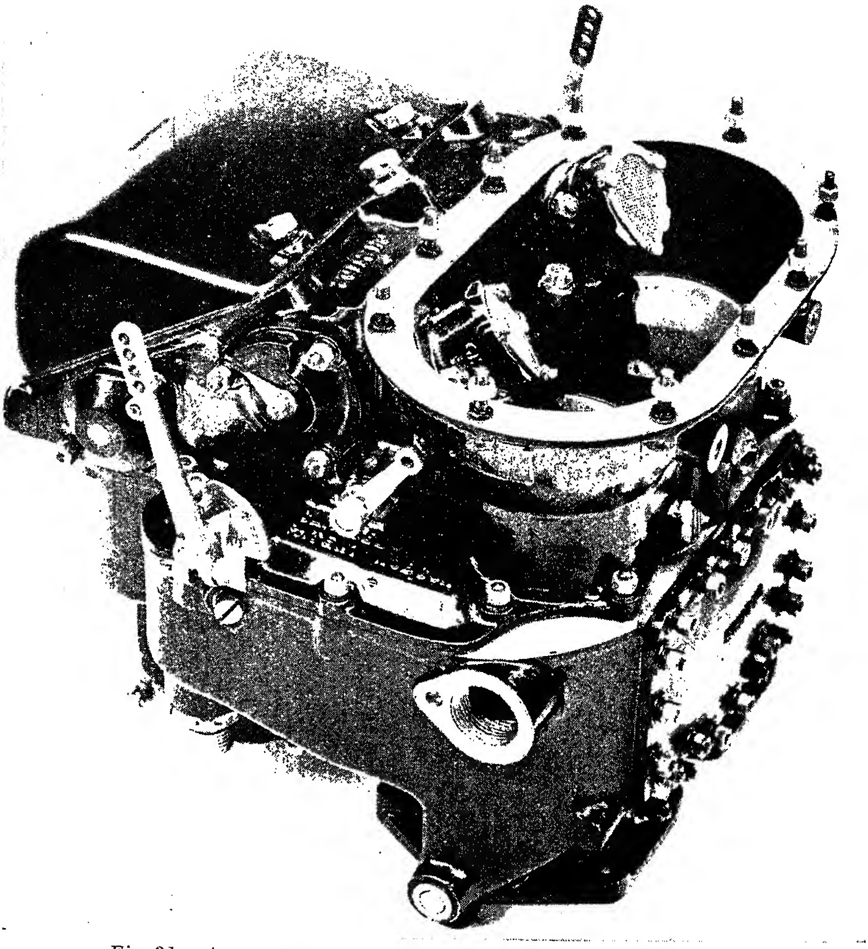


Fig. 31.—A TWIN MASTER CONTROL CARBURETTER, INVERTED TYPE.
There are only two levers to connect to the pilot's cockpit control.

of engine revs., power output and mixture strength ; the whole combination being entirely automatic.

DE-ICING OF INDUCTION SYSTEMS

The removal of ice from inside carburetters and induction systems is a problem that has exercised the minds of aviators for a long time. Ice forms for two reasons, firstly a suitable combination of low temperature and humidity of the air entering the carburetter and, secondly, the drop in temperature due to evaporation of the fuel as it passes into the air

stream. The use of oil-heated induction elbows minimises slow ice deposit at this point, but only partially, as does hot air entering the carburetter, but freezing is sometimes so severe that if sufficient hot air is used to eliminate it, detonation and a serious drop in power accompanies it.

Freezing in the Induction System

Freezing in the induction system causes a gradual loss of power, excessive consumption, jammed throttles and sometimes forced landings, and when a gradual drop in engine speed indicated ice formation, one method of dislodging it was to weaken off the mixture by means of the mixture control until violent backfires took place through the carburetter. While this was often effective, it was a dangerous proceeding, as the ice was dislodged in a lump and drawn into the engine with the risk of damaging the supercharger impeller and lodging under the valves, apart from the risk of fire breaking out or the engine stopping.

The Remedy

A short time ago it was discovered that by adding certain liquids to the fuel passing through the carburetter, freezing could be prevented. Some of these were either prohibitive in price or corrosive, and the best proved to be a type of alcohol known as de-natured Ethanol. It was also found that mixing the alcohol with the engine fuel brought about certain disadvantages—such as the collection of water in the fuel tank and carburetter float chamber—and the best way was to keep the alcohol in a separate tank and fit the carburetter with a special connecting pipe that mixed the alcohol and fuel just before the latter entered the air stream. Commercial methylated spirit should not be used except in an emergency on account of the water it contains and its highly corrosive action on aluminium.

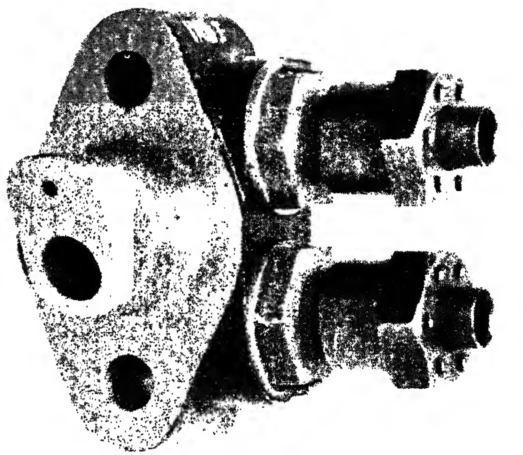


Fig. 32.—THE INDUCTION PIPE DETECTOR UNIT SHOWING SMALL (FREEZING) HOLE AND LARGE (NON-FREEZING) HOLE.

One and a half times full size.

A maximum proportion of alcohol equal to 3 per cent. of the total fuel used is found to be sufficient to prevent con-

Fig. 33.—THE HOBSON-SWAN ALCOHOL DE-ICER FOR ENGINE INDUCTION SYSTEMS.
Two-thirds full size.

tinuous freezing under the worst conditions, and in order to make the use of alcohol entirely automatic the Hobson-Swan Ice Eliminator was invented and patented.

The Hobson-Swan Ice Eliminator

This eliminator consists essentially of two parts, a detector in the induction elbow where freezing first starts and a device which feeds alcohol to the special carburetter connection only when the detector indicates ice formation. The detector consists of a projection into the interior of the induction elbow and cut off at a slant so that the sloping face opposes the direction of the air stream. In this face are two holes, one small, known as the " freezing orifice " and the other large, known as the " open orifice." These two holes are connected by piping to unions on the alcohol control unit. In principle this unit consists of two parts, a float-chamber fed from the alcohol tank and a flexible diaphragm of special fabric enclosed in a casing, the diaphragm being so connected to the float mechanism that movement of the diaphragm in one direction

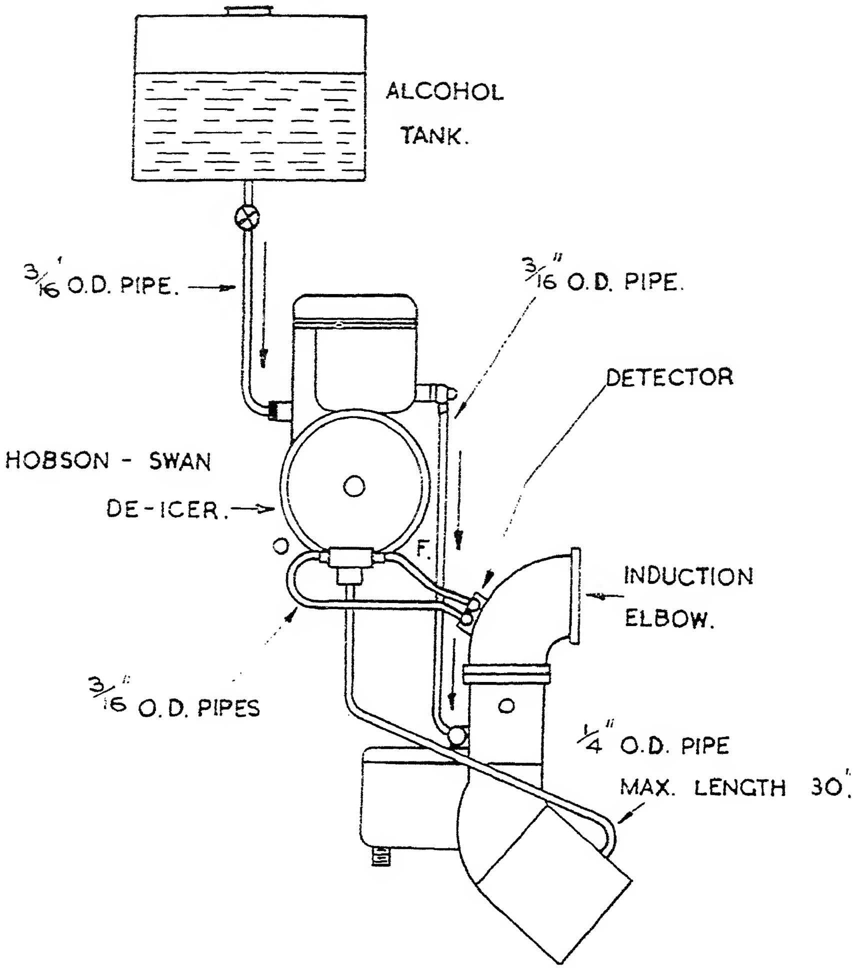


Fig. 34.—INSTALLATION DIAGRAM OF HOBSON-SWAN ALCOHOL DE-ICER.

frees the float mechanism and allows alcohol to flow and movement in the other locks it, thereby stopping the flow.

The two holes in the detector unit are connected one to each side of the diaphragm. When the engine is running there is a depression in the induction elbow, and this depression is transmitted *via* the detector holes and piping to the diaphragm casing. If no ice is present, both holes are open, with the result that the depression is equal on both sides of the diaphragm and it remains stationary in the position that locks the float chamber mechanism.

If ice starts to build up on the detector, the small hole rapidly becomes

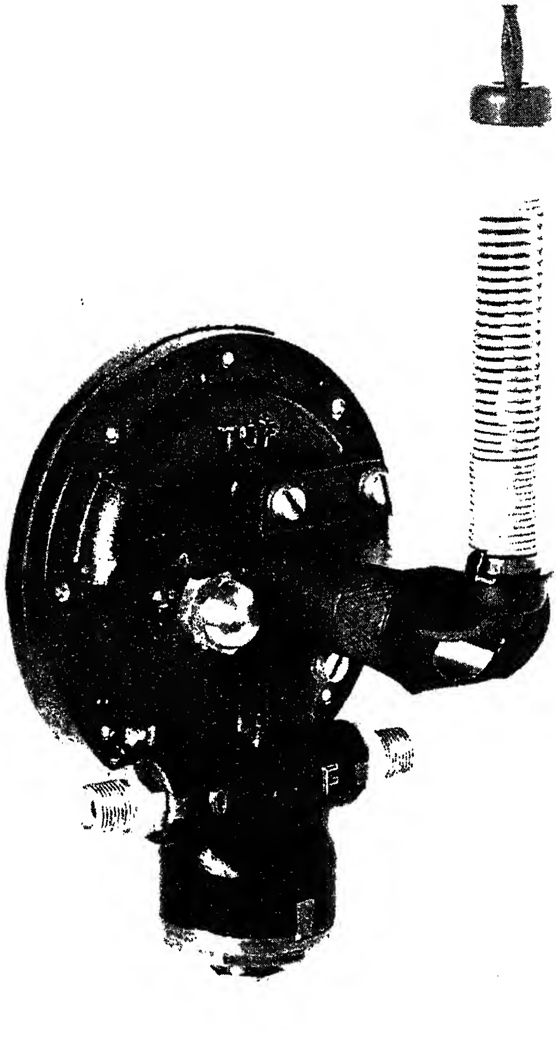


Fig. 35.—THE HOBSON ELECTRICAL ICE WARNING UNIT FOR INDUCTION SYSTEMS.
Two-thirds full size.

choked, with the result that all the depression is placed on one side of the diaphragm. This is at once pulled hard over, thereby freeing the float-mechanism and allowing alcohol to pass to the carburetter. This dissolves the ice by considerably lowering its freezing point, and as soon as both detector holes are once more open, the diaphragm is free to return to its original position, thereby cutting off the alcohol until such time as ice forms again. The instrument therefore is entirely automatic and only uses the minimum quantity of alcohol necessary to deal with such ice formation as takes place.

It forms an ideal combination with the electrical ice-warning unit, a description of which follows, as the latter warns the pilot when ice is forming as well as when the de-icer is working. As ice formation in the induction system is often accompanied by ice formation on the aeroplane, it is a hint to the pilot to find if possible some

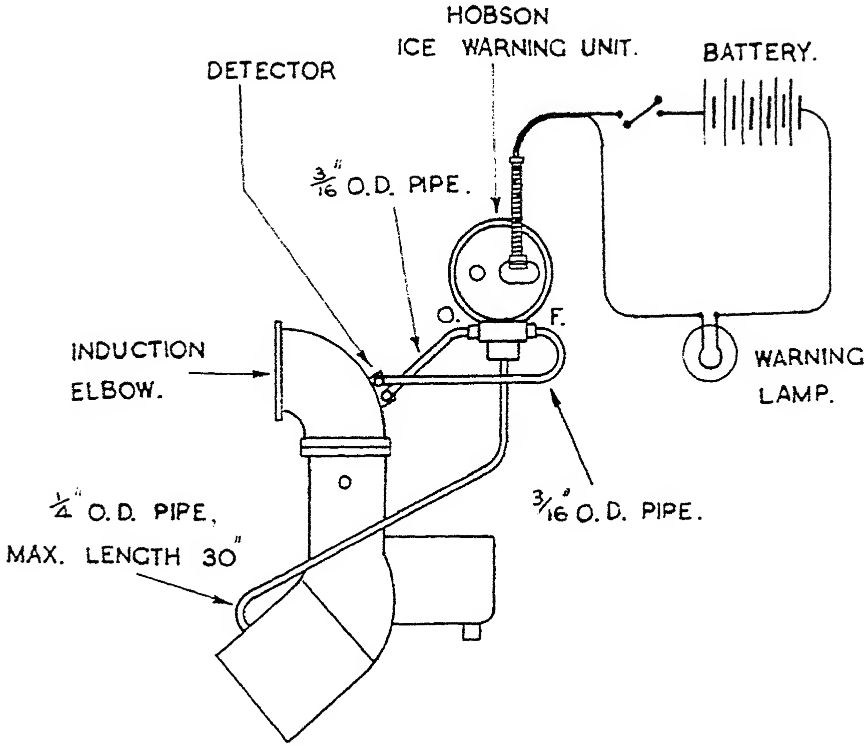


Fig. 36.—WIRING DIAGRAM FOR HOBSON ELECTRICAL ICE WARNING UNIT FOR ENGINE INDUCTION SYSTEMS.

other altitude where atmospheric conditions are such that icing does not occur.

Fig. 32 shows the detector which serves for either the alcohol de-icer or the electrical warning unit, and Fig. 33 shows the alcohol de-icer. An installation diagram is shown in Fig. 34.

The Hobson Electrical Ice-warning Unit

The warning unit consists of a casing and a diaphragm, each side of which is connected by piping to the induction pipe detector in the same fashion as the alcohol de-icer, but instead of operating float-chamber mechanism when freezing takes place, makes electrical contact between two platinum points. By means of the aeroplane battery, a red warning lamp in front of the pilot and the necessary wiring, visual warning is given to the pilot of ice formation in the induction system.

The instrument is suitable for any voltage, and a switch should be incorporated somewhere in the circuit, in order that if required the device can be isolated from the battery. Connection is made to the warning

unit by means of insulated plugs, which completely cover all parts electrically alive; they are held in place by a stirrup fixed to the instrument by three screws. The electrical system is completely insulated, so that no "earth" exists in the instrument; the electrical contacts are specially finished to a mirror surface and are unaffected by the passage of current for long periods.

The warning unit should be placed at a point slightly higher than the induction pipe detector and at a point where it is not subjected to excessive heat and vibration from the engine.

The Detector

The actual angle of the portion projecting into the induction pipe has to be found by experiment, and in order to do this the engine should be run at all throttle openings from slow-running to full throttle, a mercury U tube being connected to the two unions on the detector. The angle should be such that at no time is there a difference in pressure between the two detector holes of more than 2 in. of mercury, and the greatest depression should always exist on the small or freezing hole.

Both the alcohol de-icer and the electrical warning unit are adjusted before they leave the factory to work to a minimum induction pipe depression equal to ½ in. of mercury and the adjustment sealed. Screwing the adjusting screw inwards raises the minimum depression at which the warning unit works. The lower ends of both devices contain a fine gauze filter through which a small quantity of air flows continuously: this filter should be removed and cleaned periodically, and the pipe connected to it taken to a source of clean air supply at approximately atmospheric pressure such as the carburetter air intake. It is important that the unions marked "O" and "F" are not wrongly connected or the instruments will not work.

Where multi-bore carburetters are used with all bores feeding into a common induction system, the detector is preferably placed in the bore feeding the richest mixture as is often the case when auxiliary jets are fed into one bore only, the reason being that the richer the mixture, the greater the rate of evaporation and therefore the bigger temperature drop.

The action of these instruments can be checked experimentally at any time when the engine is running and no freezing present. The pipe connecting the freezing orifice to the instrument should be removed and replaced by one having a joint in it made of rubber tubing. Squeezing the tube stops the air flow in the same way as ice does and the instrument should operate. The size of the various orifices, both in the detector and the two instruments, have been found as the result of prolonged testing and must on no account be altered. Fig. 35 shows the electrical ice warning unit and Fig. 36 the wiring diagram.

Factory Testing of Carburetters and Automatic Controls

Every type and size of carburetter, boost control, etc., has a definite Test specification laid down by the Air Ministry, and every test is under the supervision of a resident member of the A.I.D. (Aeronautical Inspection Directorate), the Air Ministry department responsible for the correctness of the material used and the satisfactory functioning of the product they are supervising. Material cannot be bought except from manufacturers approved by the A.I.D. and the composition of every class of material, be it steel, brass, aluminium, etc., that may be used, is specified in what is known as a D.T.D. specification and frequent analyses and physical tests are made to ensure that the various materials conform to the specification. The tracing of each part, from which blue prints are made and issued to the workshops, has to be approved and stamped as such by an Air Ministry official, not only as to material, but as to general proportions, design and fitness for the part it has to play in the article of which it is a component. Every carburetter, boost control, etc., is given a serial number and a complete record is taken of its test performance at the factory and it may not leave the factory unless accompanied by an A.I.D. release certificate. The same applies to spare parts for replacements, etc.

Rigid Control of Material and Workmanship

This regulation immediately places an aero engine carburetter—apart from the infinitely finer workmanship—on a very much higher plane than an ordinary automobile engine carburetter, and its test at the engine manufacturer's plant is also under A.I.D. observation. Should any defect become apparent during engine test, it can only be returned to the makers *viâ* the engine manufacturer's A.I.D. department, so it will be seen that practically from the very start, to the end of its useful life, the carburetter's history is known and is under official observation.

Prototype Carburetters

When a new type of carburetter, boost control, etc., is tested and tuned on an engine and the setting is considered to be a satisfactory one for production purposes, the carburetter is returned to the maker's factory and in the presence of the engine maker's representative and a member of the A.I.D. it is given what is known as a " blower test " to establish an agreed set of conditions by which all future carburetters of that type can be adjusted before they leave the factory, with the assurance that they will, when mounted on an engine, repeat the performance given by the first one.

Amongst other particulars which have to be recorded are the following :—

Complete setting, *i.e.*, chokes, jet, type of diffuser, power jet timing ; also the minimum angle to which the carburetter can be tilted without

flooding at the maximum fuel pressure. The free flow of fuel through the carburetter at two different pressures must also be checked, to verify that the required excess of flow over the maximum that the engine can ever use is available. The percentage of mixture control for altitude that can be obtained is also specified, also fuel-level in the float chamber and the amount of fuel discharged when the accelerating pump is operated. The latter is obtained by opening the pilot's throttle lever on the carburetter *quickly* three times in succession, the discharged fuel being collected in a measuring glass and the amount per pump stroke obtained thereby.

Blower Test Plant

This consists mainly of a suitable suction air pump, a tank large enough to damp out all pulsations in the air flow and a means of fixing the carburetter, so that the air can be drawn through it. A fuel tank is connected to the carburetter with a flow-meter interposed, so that for any throttle opening or suction given by the pump, the pints per hour of fuel flowing through the carburetter can be seen. A more elaborate form of plant is that in which the weight of air passing through the carburetter can be measured. This reading in conjunction with the fuel

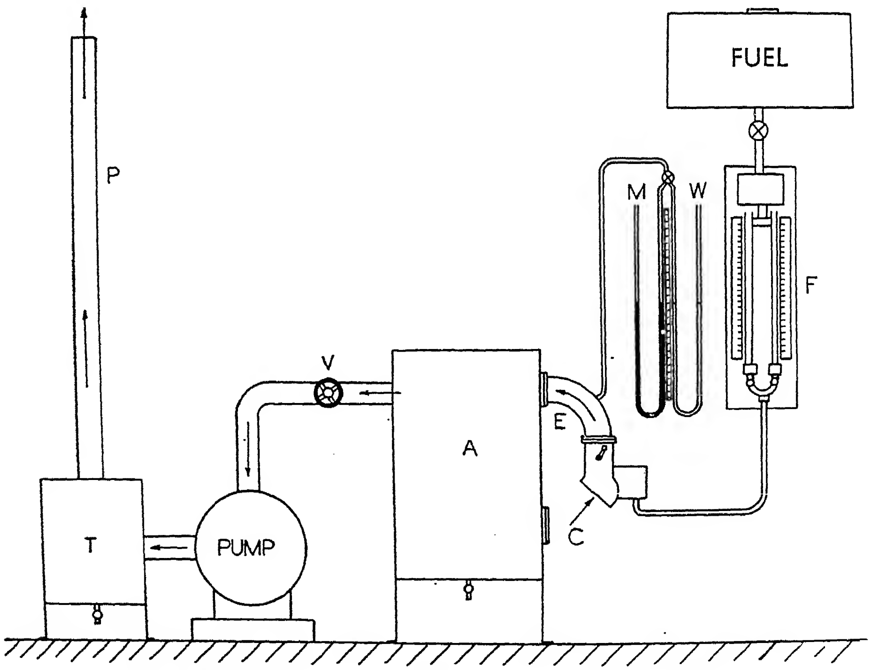


Fig. 37.—THE LAYOUT OF A PRODUCTION BLOWER TEST PLANT.

flow gives the fuel-air ratio, but for production purposes it is only necessary to know the fuel flow and suction placed on the carburetter. For low suctions such as occur at full throttle, a U-tube filled with water is mainly used, whilst for high suctions which occur under closed throttle (slow running) conditions a U-tube filled with mercury is used.

Fig. 37 shows diagrammatically a blower plant. "A" is the pulsation damping tank connected on one side to the pump and on the other to the elbow on which the carburetter is fixed. Between the tank and the pump is an adjustable valve by means of which the flow of air can be varied. Air enters the carburetter intake at "C," passes through the elbow "E," at which point the depression or suction placed on the carburetter is measured by means of the mercury gauge "M" or the water gauge "W," a two-way cock enabling either to be used as desired. Fuel passes through the flow-meter "F" and so to the carburetter float chamber. A suitable lever is connected to the carburetter throttle so that it can be held at any desired opening, a pointer and scale graduated in degrees being attached so that the exact angular opening of the throttle can be checked. When the valve "V" is opened, air and fuel pass from the carburetter through elbow "E" and tank "A." It then passes through the pump

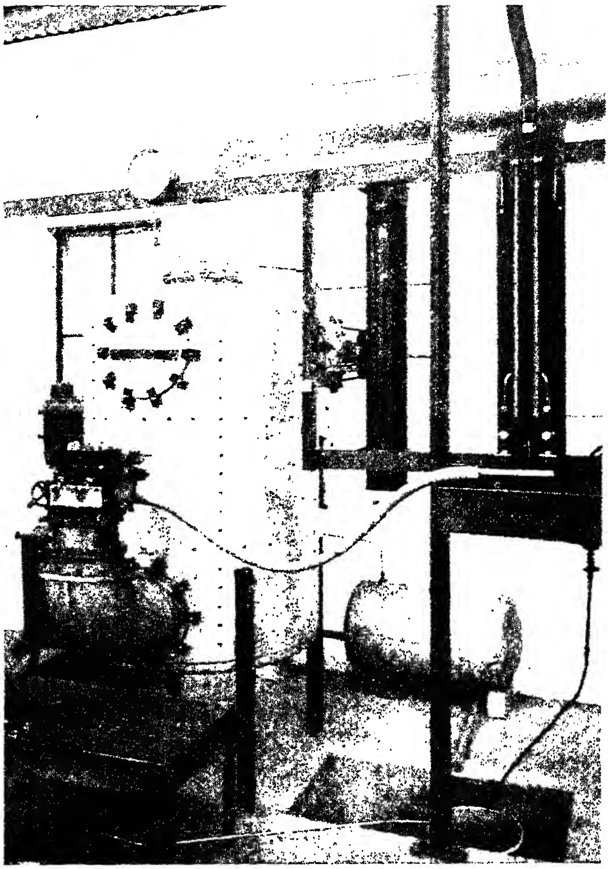


Fig. 38.—BLOWER TESTING AN INVERTED CARBURETTER.

Note the position of elbow and connecting pipe from flow-meter to carburetter float chamber connection. The small tank in the background on the floor is for storing the reclaimed fuel.

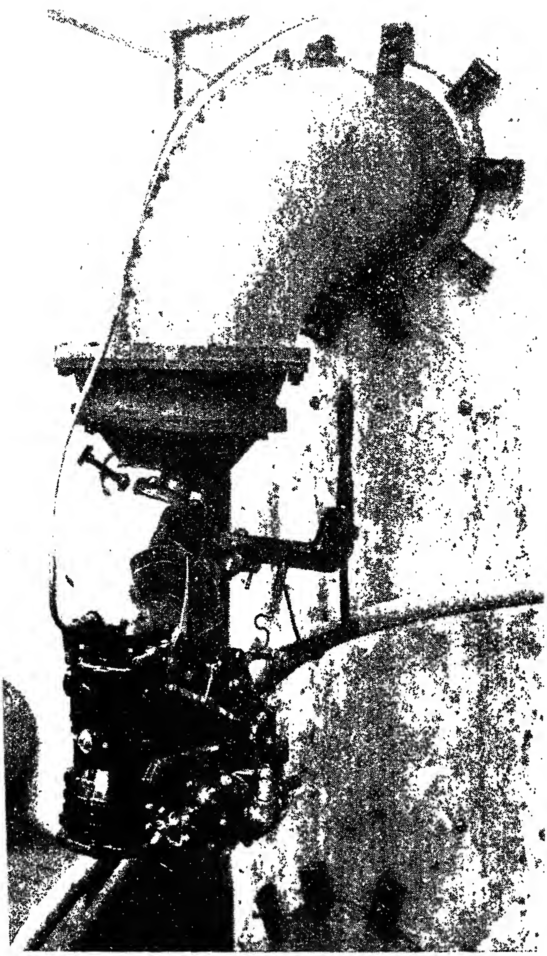


Fig. 39.—A VERTICAL MASTER CONTROL CARBURETTER ON TEST.

Note the pointer fixed to the throttle and the dial marked in degrees opening.

into the fuel reclaiming tank "T." This contains baffle plates on which a proportion of the fuel—about 2/3—is deposited and finally collected in the bottom of the tank, where it can be drained off or allowed to run into a storage tank.

In some installations the tank "T" is not used separately, the baffles being in the pulsation damping tank "A." The electrically-driven pump is of special internal contruction, no revolving steel parts—that might make a spark if any foreign matter entered — being used. The whole of the air and the unreclaimed fuel are exhausted into the outside atmosphere by means of the tall pipe or chimney "P."

As in some cases the adjustment given by the wheel-valve "V" be too coarse in its regulation of the suction in the elbow "E," an additional small valve is often fixed on the tank which allows a small proportion of air to enter, forming as it were a micrometer adjustment for the depression in the tank and elbow.

Functional Tests

Readings are taken at the depressions and throttle openings established with the first test carburetter and any carburetter not coming within the

specified maximum and minimum fuel flow is returned to the works for examination as to the cause.

Fig. 38 shows a downdraught carburetter on test. The tank will be seen to have two removable manholes, the lower one being used for downdraught carburetters and the upper one for vertical (updraught) carburetters. Fig. 39 shows a vertical type Master Control Carburetter on test and viewed from the boost control side. The pointer and graduated dial can be seen, also the throttle control lever. The boost control piston is held in the "altitude" position by means of a strong spring, so that the carburetter throttle is strictly controlled by the movement of the hand lever and cannot alter through the boost control piston wandering. No oil pressure is of course supplied to either the boost control or the Automatic Mixture Control, as these units have already been tested for accuracy on a separate test rig, as previously explained. (See Figs. 13, 19 and 20.)

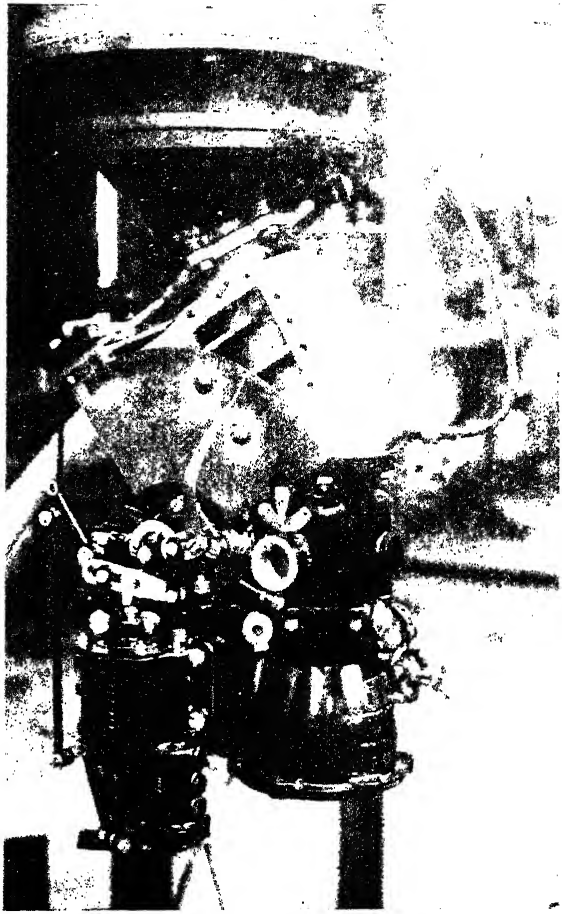


Fig. 40.—BLOWER TESTING.

A pointer fixed to the altitude (mixture) cock moves across a graduated dial to check correct weakening of mixture strength against cock opening. Note pipe to intake elbow which goes to the depression gauge.

Fig. 40 shows the same carburetter on test, but seen from the Automatic Mixture Control side. Here again a pointer is fixed to the altitude (mixture) cock on the carburetter and the pointer adjusted so that with the cock in the ground (rich) position, the pointer is at zero. The blower plant is set in operation and the fuel flow under the set

conditions noted on the flow-meter. The piston of the automatic altitude control is then lifted by hand until the pointer shows some predetermined opening of the mixture cock. The reduction in fuel flow is noted and the percentage reduction, *i.e.*, the percentage mixture control, is calculated. The flow through the enrichment jet for take-off purposes can also be checked by moving the mixture lever to the "take-off" position, the additional fuel flow as shown on the flow-meter registering this. Flows are also taken with the power jet in and out of action, as well as the correct functioning of the slow-running cut-out.

It will be seen therefore that the complete functional test of a carburetter, as well as mixture controls, takes a considerable amount of time and work apart from the power used to operate the pump, etc.; the fuel used, in the case of large carburetters, often amounts to several gallons per carburetter, some of which is irretrievably lost.

PRINCIPLES OF FLIGHT

SECTION II

Scale Effect—Effect of Wind Speed

THE wind speed was more or less constant in the previous pictures (see section I, page 105). They therefore only show the effects of shape and angle of attack on the air flow.

Figs. 1 to 3 show the effects of varying wind speed. The lateral distance between the spots of hot air is a measure of the wind speed, the further they are apart the greater the wind speed.

Fig. 1 (*a*) to (*d*) show the air flow round a so-called streamline body at increasing wind speeds.

Fig. 1 (*a*).—The air commences to move smoothly round the body.

Fig. 1 (*b*).—Large vortices develop.

Fig. 1 (*c*).—The vortices break down and the wake becomes extremely turbulent at increased speed.

Fig. 1 (*d*).—When the speed has increased sufficiently, the wide turbulent wake closes up and the body becomes a good streamline shape at this and the higher wind speeds of normal flight.

It is clear from these pictures that a body which is streamline at high speeds will almost certainly not be streamline at all at very low speeds.

Fig. 2 (*a*) to (*c*) show the air flow round an aerofoil at increasing wind speeds.

Fig. 2 (*a*).—Although the angle of attack is well above the normal stalling angle, the air commences to move down over the top of the aerofoil.

Fig. 2 (*b*).—A large vortex forms.

Fig. 2 (*c*).—The vortex breaks down and the turbulent wake, which is typical of the stall, forms at higher wind speed.

The effect of speed on the stalling angle of an aerofoil is shown in Fig. 3 (*a*) to (*e*).

Fig. 3 (*a*).—Shows an aerofoil stalled at a small angle of attack at a low wind speed.

Fig. 3 (*b*).—The wind speed has been increased and the aerofoil has unstalled.

Fig. 3 (*c*).—The wind speed has been kept constant and the angle of attack has been increased until the aerofoil stalls again.

Fig. 3 (*d*).—The wind speed has been further increased and the aerofoil has again unstalled.

Fig. 3 (*e*).—The high wind speed has been kept constant and the angle of attack has been increased until the aerofoil stalls again.

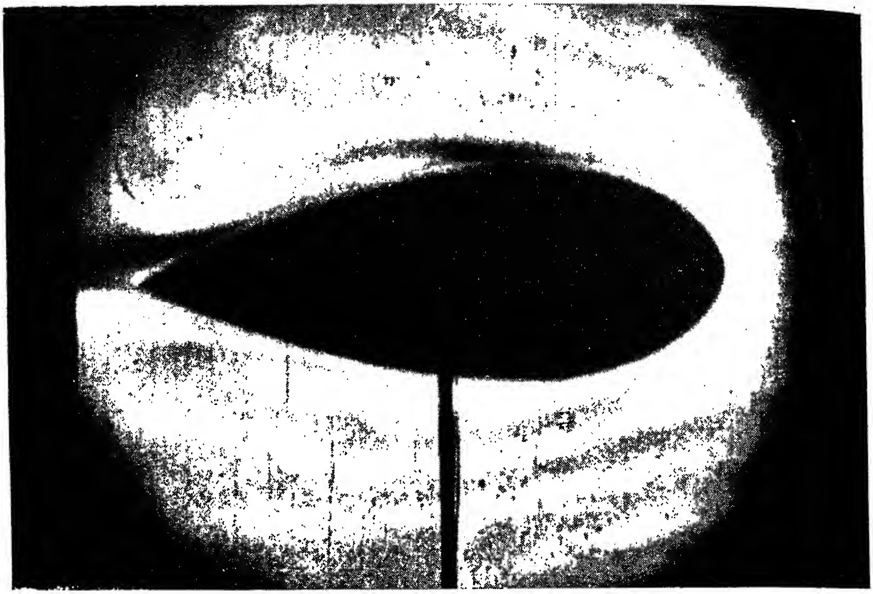


Fig. 1A.—AIR FLOW ROUND A SO-CALLED STREAMLINE BODY AT INCREASING WIND SPEEDS.
The air commences to move slowly round the body.

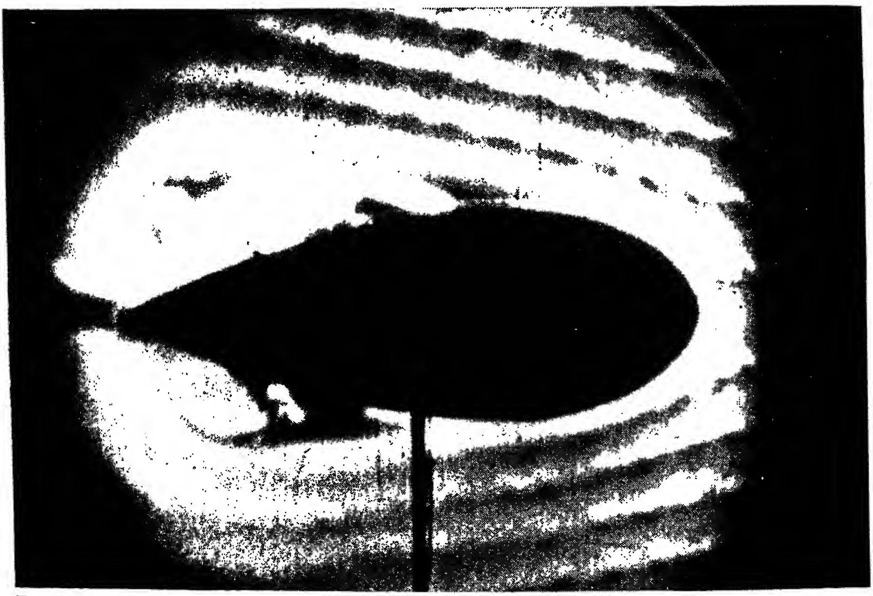


Fig. 1B.—AIRFLOW ROUND A SO-CALLED STREAMLINE BODY AT INCREASING WIND SPEEDS.
Large vortices develop.

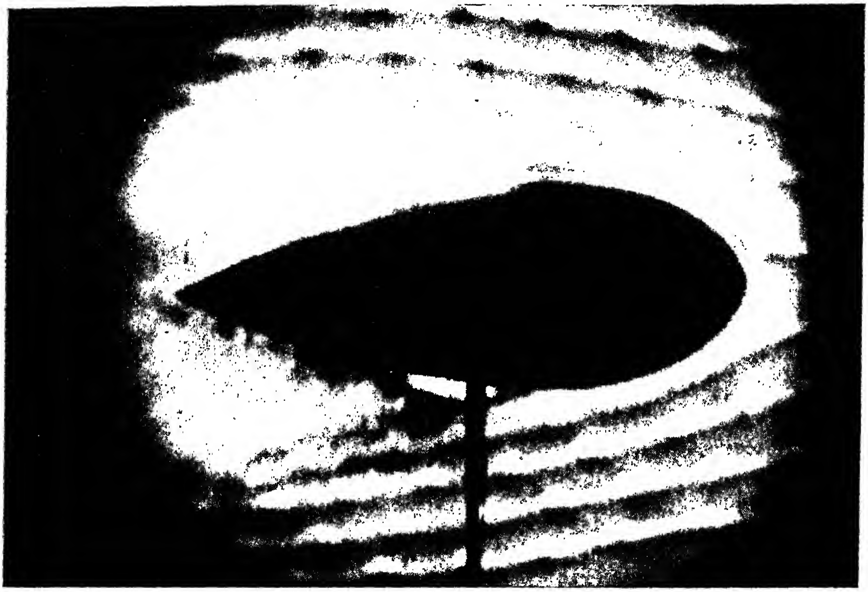


Fig. 1C.—AIRFLOW ROUND A SO-CALLED STREAMLINE BODY AT INCREASING WIND SPEEDS. The vortices break down and the wake becomes extremely turbulent at increased speed.

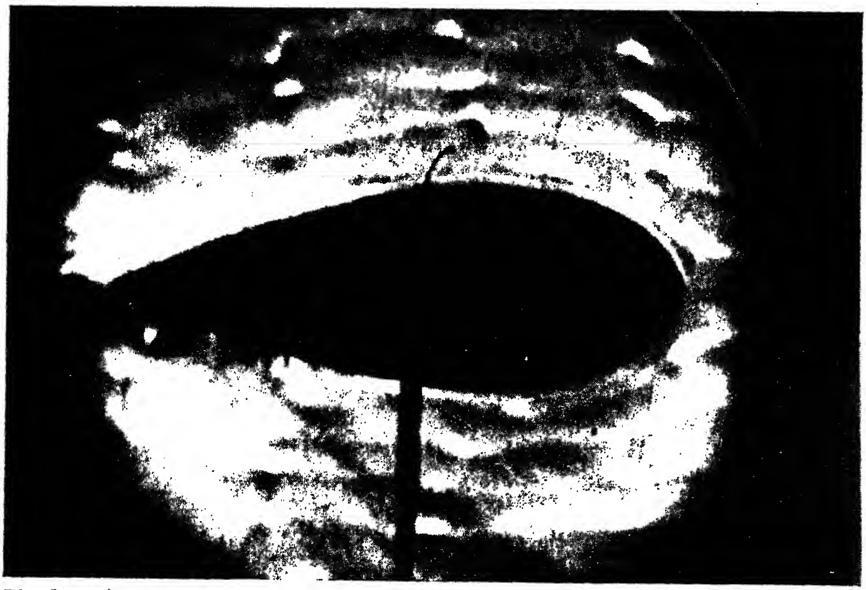


Fig. 1D.—AIRFLOW ROUND A SO-CALLED STREAMLINE BODY AT INCREASING WIND SPEEDS. When speed is sufficiently increased the turbulent wake closes up.

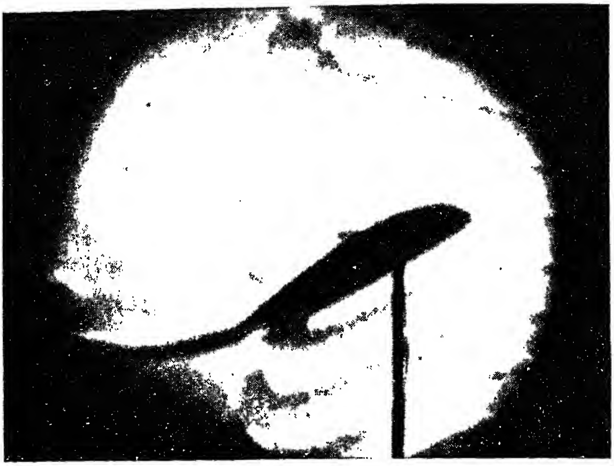


Fig. 2A. (*left*).—AIR FLOW ROUND AN AEROFOIL AT INCREASING WIND SPEEDS.

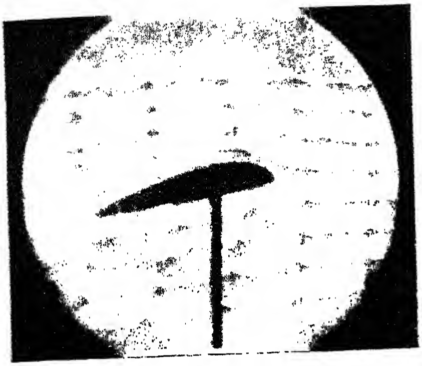
Although the angle of attack is well above the normal stalling angle, the air commences to move down over the top of the aerofoil.

Fig. 2B (*right.*)—AIR FLOW ROUND AN AEROFOIL AT INCREASING WIND SPEED.

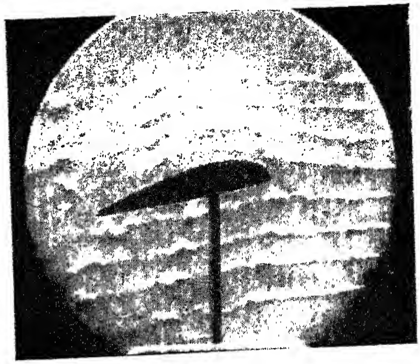
A large vortex forms.

Fig. 2C (*left.*)—AIR FLOW ROUND AN AEROFOIL AT INCREASING WIND SPEED.

The vortex breaks down and the turbulent wake, which is typical of the stall, forms at higher wind speed.

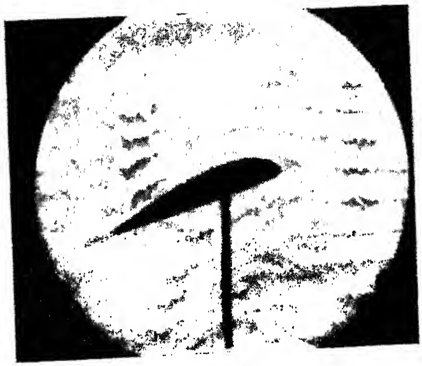


(a)



(b)

(c)



(d)

(e)

Fig. 3.—EFFECT OF SPEED ON STALLING ANGLE OF AN AEROFOIL.

(a) An aerofoil stalled at a small angle of attack at a low wind speed.

(b) The wind speed has been increased and the aerofoil has unstalled.

(c) The wind speed has been kept constant and the angle of attack has been increased until the aerofoil stalls again.

(d) The wind speed has been further increased and the aerofoil has again unstalled.

(e) The high wind speed has been kept constant and the angle of attack has been increased until the aerofoil stalls again.

Note how the size of the stalling angle has increased in Fig. 3 (c) and again in Fig. 3 (e), due solely to increased wind speed. There is, of course, a maximum angle of attack at which no further increase in wind speed will unstall an aerofoil.

Scale Effect—Effect of Size

The same sort of thing would happen if, instead of increasing the wind speed, the size of the aerofoil were increased.

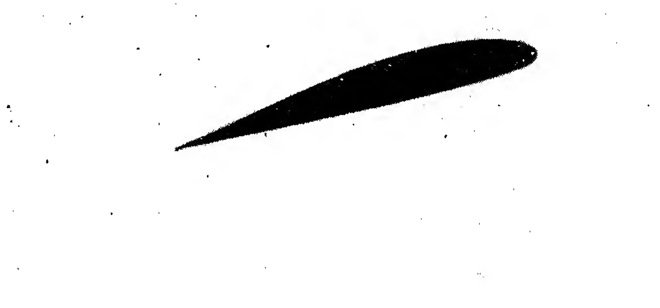


Fig. 4A.—AN AEROFOIL STALLED IN A SLOW AIRSTREAM.

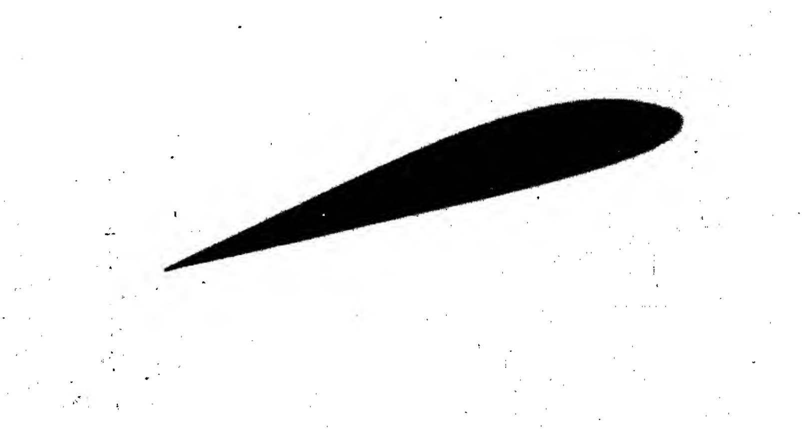


Fig. 4B.—IF THE SIZE OF THE AEROFOIL IS INCREASED SUFFICIENTLY IT WILL UNSTALL.

Fig. 4 (*a*) represents an aerofoil stalled in a slow airstream. If its size is increased sufficiently, keeping its shape and angle of attack the same, it will unstall (Fig. 4 (*b*)). These drawings are rather exaggerated to show the effect.

It is instructive to note that increasing the size of the aerofoil increases the radius of curvature, that is to say, it reduces the curvature of the path which the air must follow in order to conform to the contour of the top surface. The bigger the aerofoil, the easier it is for the air to "get round" over the leading edge without leaving the top surface.

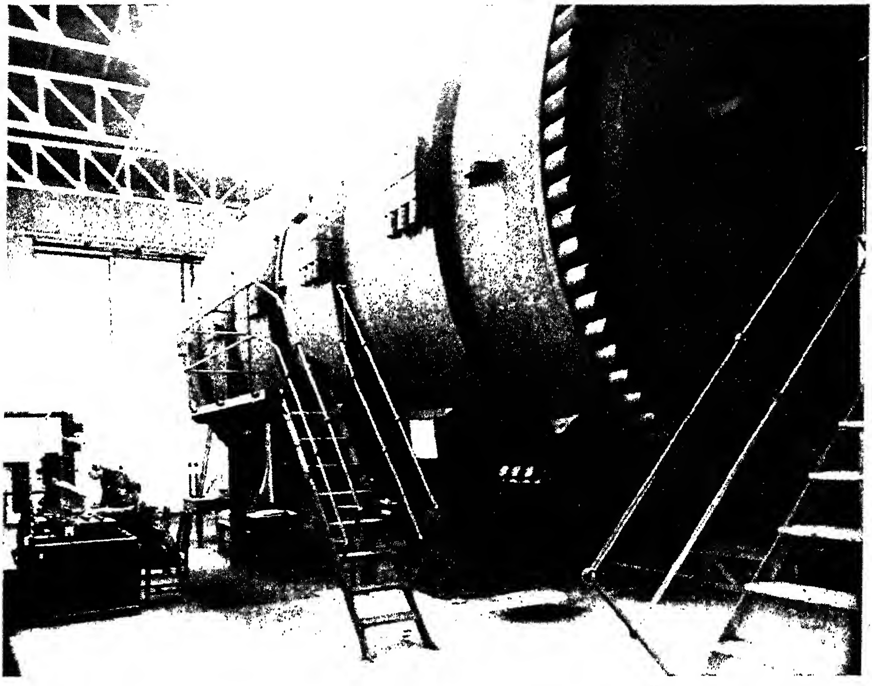


Fig. 5.—HIGH PRESSURE WIND-TUNNEL AT THE NATIONAL PHYSICAL LABORATORY. (*By courtesy of "Flight."*)

Scale Effect—Effect of Air Density

If, instead of increasing either the wind speed or the size of the aerofoil, the density of the air is increased sufficiently, the aerofoil will unstall. The greater the density, the greater the pressure of the surrounding air and the greater the tendency for the air to follow the contour of the top surface.

It is thus obvious that the type of air flow pattern round a body of given shape and at a given angle of attack, is dependent upon the *wind*

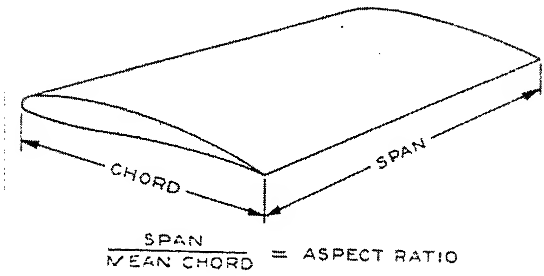


Fig. 6.—CHORD, SPAN AND ASPECT RATIO.

speed; the *size of the body* and the *density of the air*. These are the important factors in what is called scale effect.

Corrections for scale effect should be made in applying ordinary wind-tunnel measurements of the lift and drag co-efficients of model wings at low airspeeds to full-scale aeroplanes at high speeds.

Corrections for scale effect are not required in the case of measurements made in high pressure wind tunnels (Fig. 5). Air is pumped into

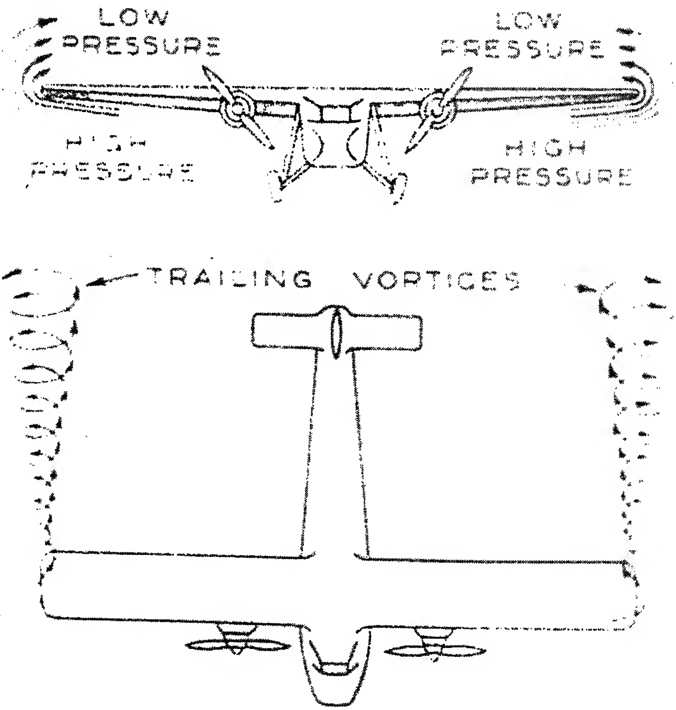


Fig. 7.—TRAILING VORTICES LEFT BY WING TIPS.
Illustrating the desirability of high aspect ratio.

such tunnels until the density of the air inside them has increased sufficiently to compensate for the relatively low wind speed and the small size of the models used.

Aspect Ratio

The ratio of the span to the chord of a wing is the aspect ratio. In the case of tapered wings, the aspect ratio is the ratio of the span to the mean chord (Fig. 6).

Since the pressure below the wings is higher than that above them, the air tends to spill upwards round the wing tips. This imposes a corkscrew motion on the flow near the tips, with the result that they leave trailing vortices behind them. These vortices require energy to produce them and they react by exerting drag (Fig. 7).

Fig. 8.—THE EFFECT OF INTERFERENCE BETWEEN BIPLANE WINGS ON PRESSURE DISTRIBUTION.

The larger the cord the smaller the aspect ratio with the same wing area and the more powerful are these trailing vortices and the greater is the drag at the same angle of attack and speed.

Long narrow wings, that is to say, wings with a high aspect ratio, are therefore more efficient than those of the same area with a low aspect ratio. They give more lift and less drag at the same angle of attack and speed.

In practice, however, aspect ratio is limited by structural requirements to 6 or 8 to 1.

Biplane Wings and Interference

When one wing is placed above another, as in a biplane, the air flow round each wing interferes with the air flow round the other wing (Fig. 8). The enclosed areas approximately

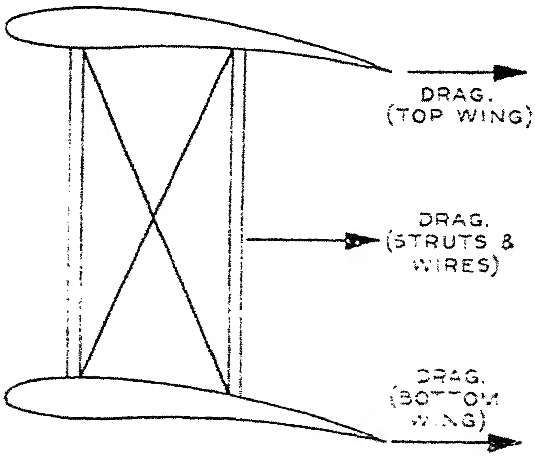


Fig. 9.—THE FURTHER BIPLANE WINGS ARE PLACED APART, THE GREATER THE DRAG OF THE NECESSARY STRUTS AND WIRES.

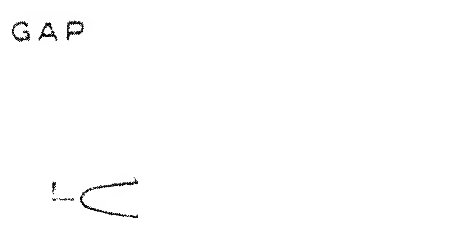


Fig. 10.—THE DISTANCE AEROPLANE WINGS ARE PLACED APART IS CALLED THE GAP.

represent the total upward forces on the under surface of the top wing and on the upper surface of the bottom wing.

The nearer the wings are to each other the greater the interference and consequent reduction of lift. The further they are apart the less they interfere with each other.

On the other hand, the further they are placed apart, the greater the drag of the necessary struts and wires which separate them (Fig. 9).

The distance aeroplane wings are placed apart is called the gap (Fig. 10).

Monoplanes and Tapered Wings

The modern tendency in design is towards the use of monoplane cantilever wings. The absence of struts and wires and of interference between the mainplanes permit monoplane wings to give the same lift for less drag than if biplane wings are used. The increased aerodynamic efficiency of high aspect ratio and structural requirements lead to monoplane wings being tapered.

Stagger

The top mainplane may be put forward or aft of the bottom main plane, that is, it may be given forward or backward stagger.

Forward stagger usually gives a larger forward angle of vision (Fig. 11). It results in less interference between the mainplanes and therefore more lift for the same drag.

Equilibrium

A body is said to be in equilibrium when the forces acting on it cancel each other out completely and so leave no resultant force or moment tending to disturb its state of rest or steady motion.

Bodies in a state of rest or of steady motion are, therefore, in equilibrium.

Stability

A body is said to be in a stable state of rest when, if slightly dis placed, it tends to return of its own accord to its original position.

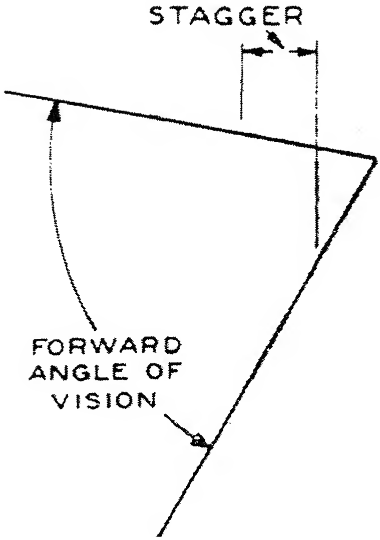


Fig. 11.—EFFECT OF STAGGER ON THE PILOT'S FORWARD ANGLE OF VISION.

Similarly, a body is said to be in a stable state of motion when, if slightly disturbed, it tends to return of its own accord to its original motion.

Instability of Cambered Wings

The centre of pressure of a cambered wing is defined as the point on the chord through which the resultant force passes (Fig. 12).

Most unstalled cambered wings are unstable in flight because their centre of pressure moves forward when the angle of attack is increased, which tends to turn the leading edge upwards and further increase the angle of attack. If not checked this would result in the centre of pressure moving still further forward.

Similarly, if any disturbance reduces the angle of attack, the centre of pressure moves aft and tends to reduce the angle of attack still further.

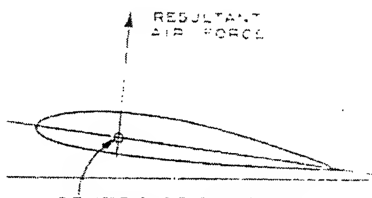


Fig. 12.—THE CENTRE OF PRESSURE OF AN AEROFOIL.

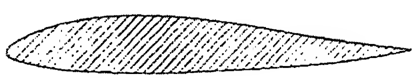


Fig. 13.—AN AEROFOIL SECTION, THE CENTRE OF PRESSURE OF WHICH IS PRACTICALLY CONSTANT AT NORMAL ANGLES OF ATTACK.

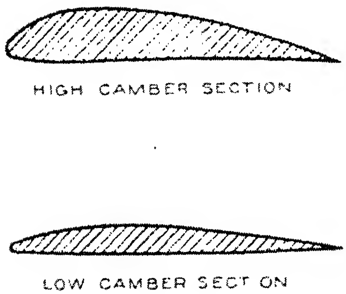


Fig. 14.—EXAMPLES OF HIGH AND LOW CAMBERED AEROFOIL SECTIONS.

Various Wing Sections

Many different shapes of wing sections have been tried. Fig. 13 is one which has been designed to have a practically fixed centre of pressure at normal angles of attack. The under surface is convex and the trailing edge is turned up slightly.

Fig. 14 shows examples of high and low cambered wing sections.

The most suitable section for the wings of any particular type of aeroplane depends upon structural requirements and the performance desired of the aeroplane. The depth of the wings must be sufficient to accommodate the structure required to support the all-up weight with the large reserve strength required to meet the increased loading due to manœuvres.

Downwash

The wings of an aeroplane deflect the air stream downwards as it flows over and under them. The angle through which the air is deflected downwards by the wings is called the angle of downwash. It varies with the angle of attack of the wings and with the distance behind the wings at which it is measured (Fig. 15).

The Centre of Pressure of an Aeroplane

The point where the resultant lift and the resultant drag of an aeroplane intersect is called the centre of pressure of the aeroplane (Fig. 16).

Airscrews

Airscrew blades are of aerofoil cross section. Their cross section varies from one of high camber at the root to one of low camber at the tip (Fig. 17).

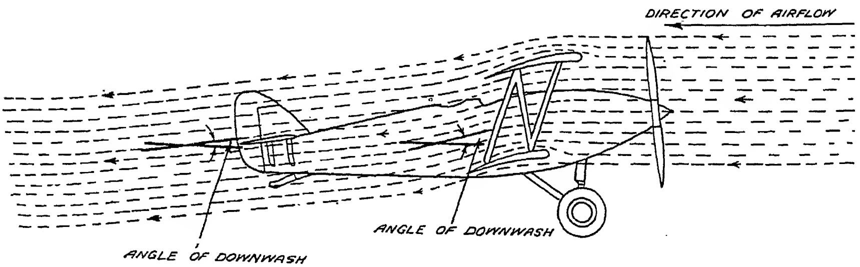


Fig. 15.—SHOWING HOW THE ANGLE OF DOWNWASH VARIES WITH THE DISTANCE BEHIND THE WINGS AT WHICH IT IS MEASURED.

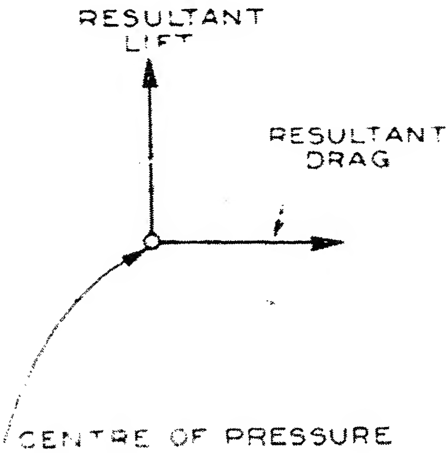


Fig. 16.—CENTRE OF PRESSURE OF AN AEROPLANE.
The point where the resultant lift and the resultant drag of an aeroplane intersect is called the centre of pressure.

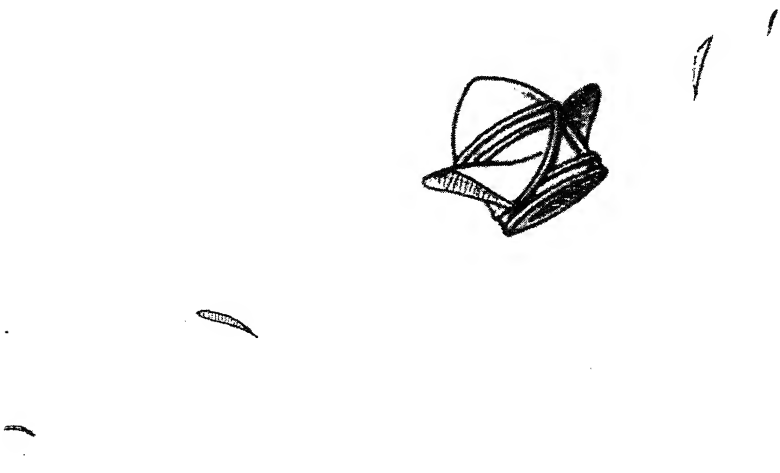


Fig. 17.—AIRSCREW BLADES.
The cross section varies from one of high camber at the root to one of low camber at the tip.

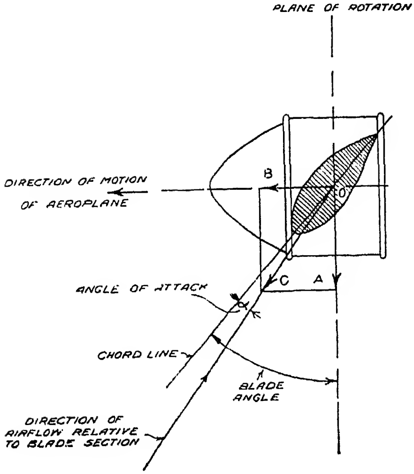


Fig. 18.—BLADE ANGLE AND ANGLE OF ATTACK OF A CROSS SECTION OF AN AIRSCREW BLADE.

If OA represents the velocity of the blade section relative to the aeroplane and OB the velocity of the aeroplane then OC represents the velocity of the blade section through the air and its angle of attack will be " a."

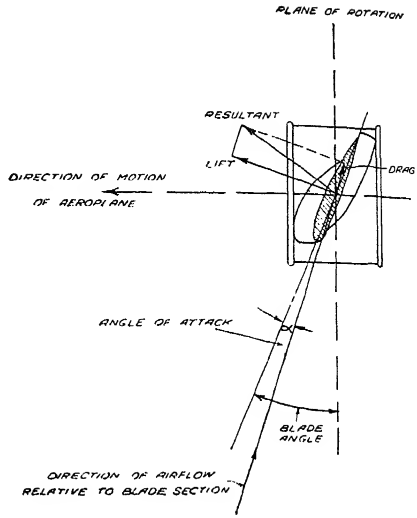


Fig. 19.—LIFT AND DRAG FORCES ON A CROSS SECTION OF AN AIRSCREW BLADE.

The acute angle between the chord of a cross section and the plane of rotation is called the blade angle of that cross section (Fig. 18).

The cross sections of airscrew blades move forward in spiral paths in flight and as the tips move faster through the air than the roots, the blade angle falls off from the root to the tip in order that the angle of attack along the blade shall be correct at normal revolutions per minute and normal forward speed.

Airscrew blades are, therefore, subjected to lift and drag forces in like manner to aeroplane wings (Fig. 19).

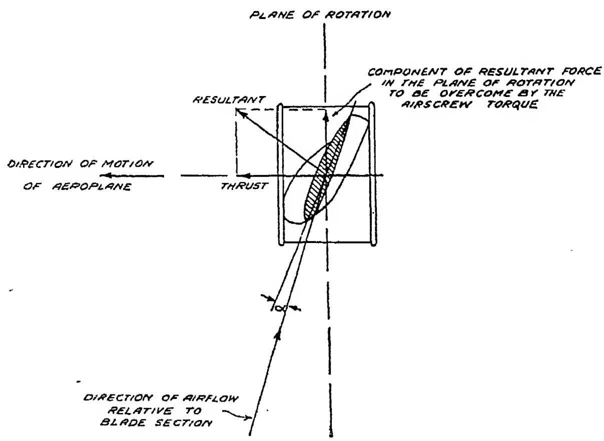


Fig. 20.—RESOLUTION OF THE RESULTANT FORCE ON A CROSS SECTION OF AN AIRSCREW BLADE INTO THE THRUST COMPONENT AND THE COMPONENT IN THE PLANE OF ROTATION.

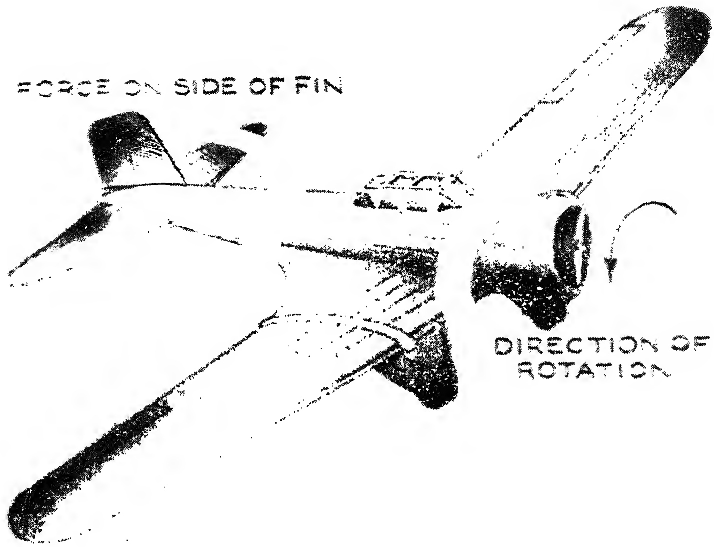


Fig. 21.—AIRSCREW SLIPSTREAM.

This illustration, highly exaggerated, shows how the rotation of the airscrew gives the slipstream a slight corkscrew motion.

The component of the resultant force in the direction of motion of the aeroplane is the airscrew thrust, while the component in the plane of rotation exerts the resisting moment or torque, which has to be overcome by the engine (Fig. 20).

The Airscrew Slipstream

The rotation of the airscrew gives the slipstream a slight corkscrew motion. This is shown grossly exaggerated in Fig. 21.

As a result of the twist of the slipstream, the air pressure on a symmetrically positioned fin will be greater on one side than on the other, and in the case shown in Fig. 22, would tend to yaw the aeroplane to port.

Fins of single-engined aeroplanes are therefore sometimes off-set slightly (Fig. 23), in order to lie symmetrically in the slipstream, or they may be cambered to produce the same effect.

Another method is to give the rudder permanent bias, in order to correct the yawing effect of the slipstream. This may be done by means of a trimming tab on the rudder (Fig. 24). The setting of this trimming tab is also grossly exaggerated.

The reaction of the airscrew torque in a single-engined aeroplane is transmitted through the engine crankcase to the aeroplane, which tends

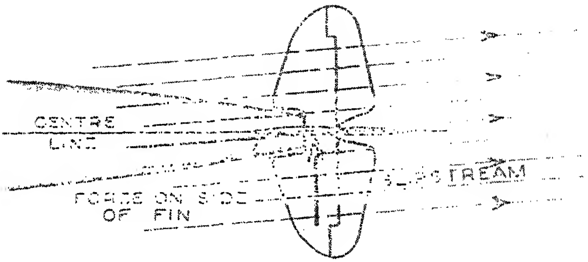


Fig. 22.—LATERAL PRESSURE OF THE AIRSCREW SLIPSTREAM ON A SYMMETRICALLY POSITIONED FIN.

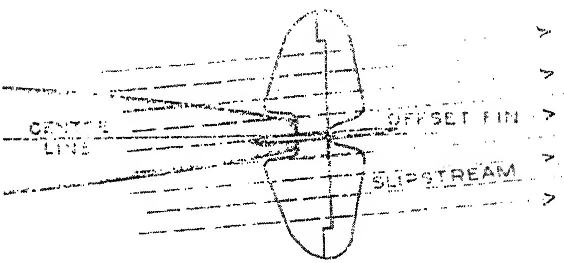


Fig. 23.—FIN OFF-SET TO LIE SYMMETRICALLY IN THE AIRSCREW SLIPSTREAM AT NORMAL R.P.M. AND FORWARD SPEED.

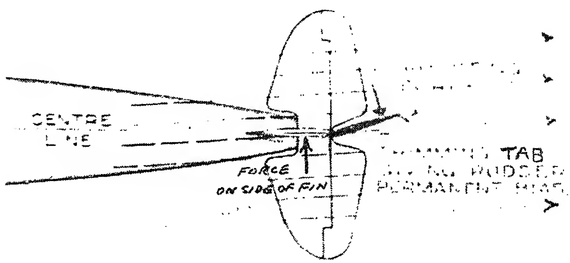


Fig. 24.—TRIMMING TAB SET TO GIVE RUDDER PERMANENT BIAS AND SO CORRECT THE YAWING EFFECT OF THE AIRSCREW SLIPSTREAM ON THE FIN.

to roll over in the opposite direction to that in which the airscrew rotates (Fig. 25).

The corkscrew motion of the slipstream impinging on the wings, produces a couple in the other direction, which tends to reduce the effect of the airscrew torque (Fig. 26).

Variable Pitch Airscrews

The pitch of an airscrew is the distance it would advance in one revolution if it gave no thrust, that is to say, if it did not slip.

The angle of attack of the blades and therefore the airscrew thrust and torque, are dependent upon the pitch, the revolutions per minute and the forward speed.

As the lift and drag of the blades varies with the density of the air, which decreases with height, the airscrew torque decreases with height, so long as the engine revolutions per minute and the forward speed remain constant.

The horse-power of super-charged engines is independent of the air density up to high altitudes.

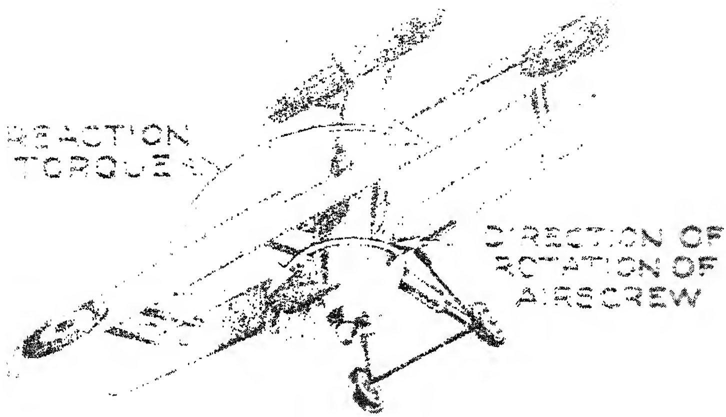


Fig. 25.—Reaction of airscrew torque in a single-engined aeroplane.

They therefore continue to develop full horse-power up to their rated height and would require to be throttled down as they gained height to prevent them from over-revving. The benefits of super-charging would thus be lost if super-charged engines were fitted with airscrews designed for flight near ground level.

In order to obtain the full benefit of super-charging, the airscrews for super-charged engines should be designed to give maximum efficiency at the rated height of the engine. The airscrew torque would increase, however, as the aeroplane descended into the denser air near ground level and the engine could not then drive the airscrew at full revolutions per minute. Maximum horse-power and thrust could not, therefore, be obtained near the ground.

If the pitch and angle of attack of the airscrew blades could be decreased when flying below the rated height of the super-charged engine, then the

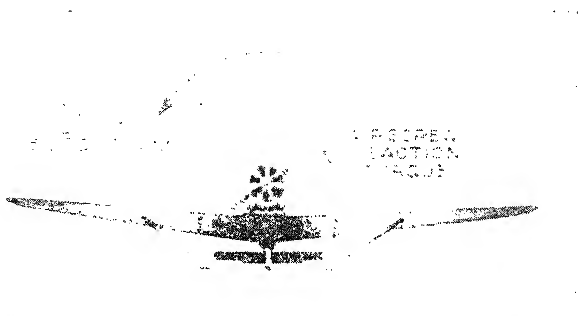


Fig. 26.—Illustrating the corrective effect of the airscrew slipstream on the airscrew reaction torque.

airscrew torque could be kept constant at all heights below the rated height. The super-charged engine would then be able to develop its full power from ground level up to its rated height.

Variable pitch airscrews are introduced on this account.

The necessary variation in pitch is obtained by turning the blades on the airscrew hub either automatically, electrically or by mechanical means under the pilot's control.

Ideally, the blades would be set at their minimum pitch and angle of attack for running up on the ground, taking off and flight at low altitudes.

As the aeroplane climbs from ground level to the rated height the blades would be turned to increase their pitch and angle of attack and so maintain constant revolutions per minute.

Above the rated height the horse-power of super-charged engines begins to fall off with increasing height, so the pitch of the airscrew should then be reduced in order to reduce the airscrew torque and permit the engine to continue to run at its most efficient revolutions per minute for the height attained.

PRINCIPLES OF FLIGHT

SECTION III

Equilibrium in Level Flight

THE streamlined fuselage shown in Fig. 1, fitted with an undercarriage, tail skid and an engine and airscrew, will run along the ground, pulled forward by the airscrew, when the engine is run fast enough. If wings are put on, it will fly level provided that :—

the *engine power* is sufficient—
to drive the *airscrew* fast enough—
to give the *thrust* required—
to overcome the *drag* of the aeroplane—
at the *speed* required—
to enable the *wings*—
to give *lift*—
equal to the all-up *weight* of the aeroplane—

and

if the four forces, *lift*, *weight*, *thrust* and *drag* have no resultant moment, tending to turn the aeroplane about its *centre of gravity*.

Looking at this in diagrammatic form (Fig. 2), at the speed at which this aeroplane is supposed to be flying, the lift is equal to the weight, the airscrew thrust is equal to the drag and the lift-weight couple has been made equal and opposite to the thrust-drag couple by positioning the centre of pressure " O " correctly in relation to the centre of gravity " G " and to the line of action of the airscrew thrust.

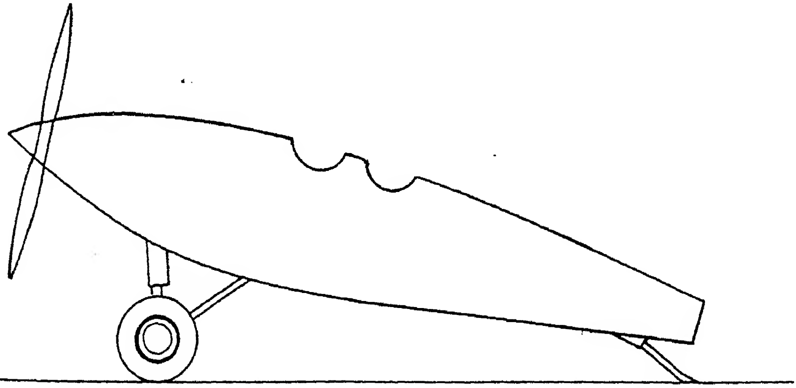


Fig. 1.—THIS FUSELAGE WOULD RUN ALONG THE GROUND, PULLED FORWARD BY THE AIRSCREW WHEN THE ENGINE IS RUN FAST ENOUGH.

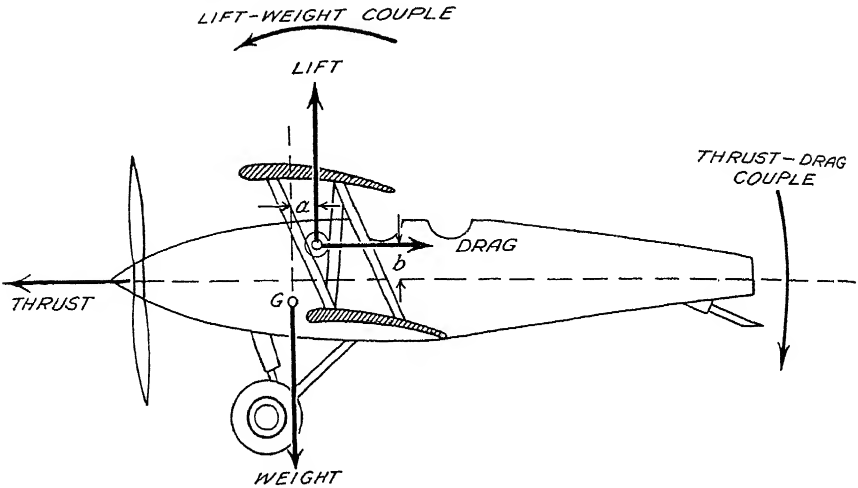


Fig. 2.—THE CONDITIONS FOR EQUILIBRIUM IN LEVEL FLIGHT ARE:

Lift = Weight.
Thrust = Drag.
Lift — Weight Couple (L × a) = Thrust — Drag Couple (D × b).

The centre of pressure can be located correctly by positioning the wings correctly and making fine adjustments on the stagger. Equilibrium in level flight can thus be achieved *at a particular speed.*

" A particular speed " is stressed because if the speed is reduced, the lift coefficient must be increased in order to keep the lift equal to the weight and so continue to fly level. The lift coefficient is increased by increasing the angle of attack of the wings. Increasing the angle of attack involves putting the nose up and this, in turn, normally results in the centre of pressure moving forward. A shift of the centre of pressure would upset the balance obtained at the previous speed.

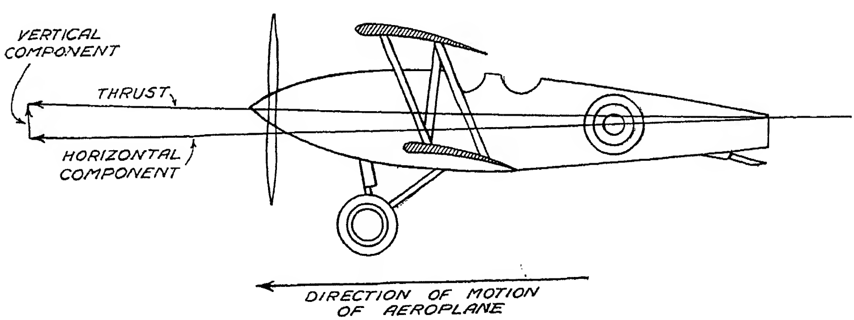


Fig. 3.—IF THE AIRSCREW THRUST ACTS AT AN ANGLE ABOVE THE HORIZONTAL IN LEVEL FLIGHT, THE VERTICAL COMPONENT OF THE AIRSCREW THRUST WILL ASSIST IN SUPPORTING THE WEIGHT WHILE ITS HORIZONTAL COMPONENT MUST BALANCE THE DRAG.

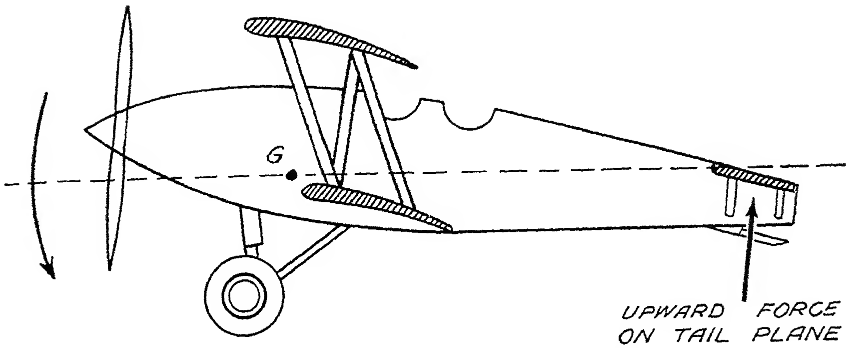


Fig. 4.—A SYMMETRICAL TAILPLANE HAS BEEN ADDED LYING WITH NO ANGLE OF ATTACK TO THE AIRSTREAM WHEN THE AEROPLANE IS IN LEVEL FLIGHT AT NORMAL SPEED.

If an upcurrent increases the angle of attack of the wings and therefore also of the tailplane, the airflow will now exert an upward force on the tailplane, tending to turn the nose down and so restore the aeroplane to its original altitude.

The airscrew thrust was shown acting horizontally in Fig. 2 for the sake of simplicity. If the airscrew thrust acts at an angle above the horizontal, its vertical component will assist in supporting the weight, while its horizontal component will have to balance the drag (Fig. 3).

STABILITY AND CONTROL

Static Stability

Although this aeroplane is in equilibrium in steady level flight, it is unlikely to be stable because, if disturbed by encountering an up-current for instance, the angle of attack will be increased and the centre of pressure will normally move forward and tend to turn the nose up still further. That is to say, if disturbed slightly this aeroplane tends of its own accord to depart further and further from level flight and is said to be longitudinally unstable.

The condition of the aeroplane in steady level flight might be likened to that of a billiard ball balanced on another ball. The aeroplane is in equilibrium in steady level flight and the billiard ball is in equilibrium while balanced on the other ball, but both are unstable. If slightly disturbed, both the ball and the aeroplane depart entirely from their original states of motion and of rest. The aeroplane ends up in a totally different state of motion, and the ball in a totally different state of rest.

Let us attach a symmetrical tailplane lying with no angle of attack to the air stream when the aeroplane is flying level at normal speed—after allowing for the downwash from the mainplanes.

The acute angle between the chord line of the mainplane and the chord line of the tailplane is called the tail-setting angle. If the aeroplane now encounters an up-current which increases the angle of attack of the

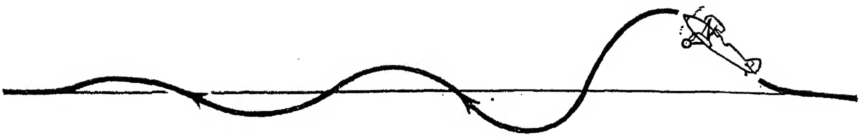


Fig. 5.—AN AEROPLANE WHICH IS STATICALLY STABLE IN LEVEL FLIGHT WILL PROBABLY SWING OR OSCILLATE IN PITCH A FEW TIMES IF IT IS DISTURBED, BEFORE SETTLING DOWN AGAIN TO STEADY LEVEL FLIGHT.

If it finally settles down again to its original motion of its own accord it is said to be dynamically stable.

wings, the angle of attack of the tailplane will also be increased and the airflow will exert an upward force on the tailplane.

The centre of pressure of the tailplane being a considerable distance behind the centre of gravity of the aeroplane, causes the tailplane to exert a larger pitching moment about the centre of gravity than that due to the shift of the centre of pressure of the wings. This tends to turn the nose down and so decrease the angle of attack of the wings again (Fig. 4).

Similarly, if the aeroplane encounters a down current, decreasing the angle of attack of the wings, the airflow exerts a downward force on the tailplane and tends to turn the nose up and restore the wings to their original angle of attack.

The inherent instability of the mainplanes at normal angles of attack is thus overcome. The aeroplane now tends, if disturbed, to return of its own accord to an even keel longitudinally.

Its state of motion in steady horizontal flight might now be likened to the state of rest of a ball in a bowl. Both are in equilibrium and

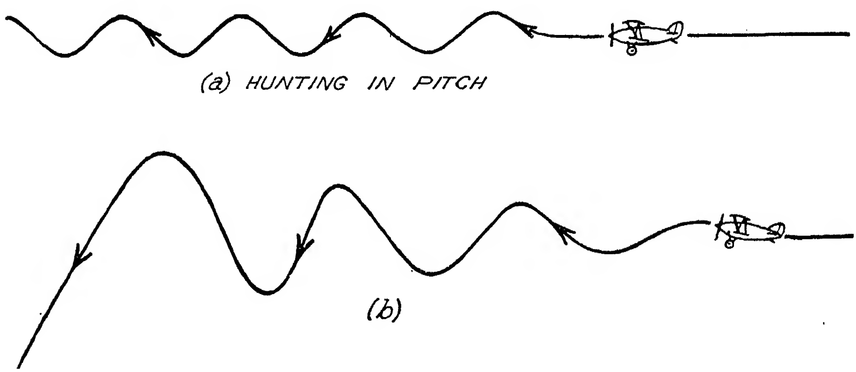


Fig. 6.—DYNAMIC INSTABILITY.

An aeroplane which is statically stable in level flight may "hunt" indefinitely if it is disturbed (*a*); or it may oscillate in pitch with increasing amplitude until it "falls" into a nose dive or stalls and nose dives (*b*). In either of these cases it would be dynamically unstable.

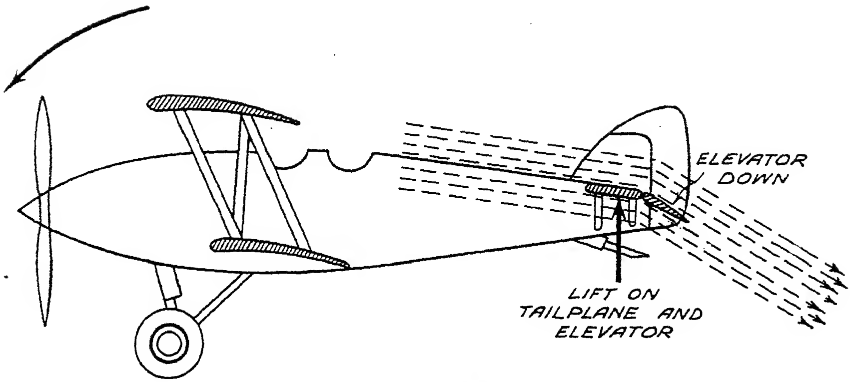


Fig. 7.—FORE AND AFT CONTROL.

When the elevator is put down a lifting force is introduced which tends to turn the nose of the aeroplane down, and *vice versâ.*

both are statically stable. If disturbed slightly, both tend to return of their own accord to their original states of motion and of rest.

Dynamic Stability

Something else may happen when the aeroplane is disturbed. Instead of settling back gradually to steady motion on an even keel, it will probably swing or oscillate in pitch a few times about its level position before it finally settles down again to steady level flight (Fig. 5).

If it finally settles down again to its original state of motion of its own accord it is said to be dynamically stable, as well as being statically stable longitudinally.

It may continue to over-shoot its level attitude and oscillate indefinitely. This is sometimes called "hunting." The nose may go on pitching up and down to the same extent every time, or to a greater extent every time, until the aeroplane "falls" completely out of its original state of motion into a nose dive or until it stalls and then nose dives. In either of these cases the aeroplane, though in equilibrium in level flight, and although statically stable, would be said to be dynamically unstable longitudinally (Fig. 6, *a* and *b*).

This may be illustrated by referring again to a ball in a bowl. When displaced the ball tends to return to its original position, but although it tends to do so, it would oscillate for ever if there were no friction. Nevertheless, it was in a statically stable position at the bottom of the bowl.

If we overcome friction by giving a ball in a bowl a push at regular intervals, then, although the tendency to return to its original position at the bottom of the bowl still exists, the ball will continue to oscillate and never return to its original position so long as the energy required to maintain its oscillatory motion continues to be supplied.

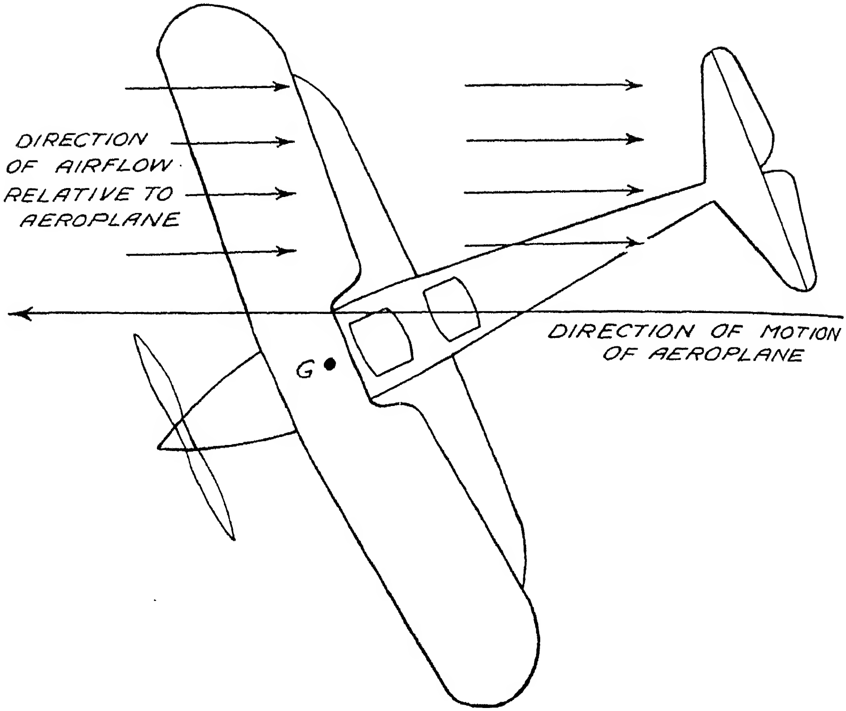


Fig. 8.—A GUST OF WIND HAS DEFLECTED THE NOSE TO PORT; THE AEROPLANE PROCEEDS "CRABWISE," SKIDDING OR SIDESLIPPING TO STARBOARD.

In the case of a dynamically unstable aeroplane the energy required to keep it oscillating in pitch is derived from the engine while it maintains its height and from gravity if it loses height.

Fore and Aft Control

To enable the pilot to raise and depress the nose at will, a hinged control surface or elevator is fitted on the trailing edge of the tailplane and connected by levers and cables to the control column in the pilot's cockpit.

When the pilot depresses the elevator he gives the tailplane and elevator effective camber with an angle of attack to the airstream, which introduces a lifting force tending to turn the nose of the aeroplane down (Fig. 7).

Similarly, when he raises the elevator he introduces a downward force on the tailplane which tends to turn the nose up.

√ Directional Stability

If a gust of wind deflects or yaws the nose of this aeroplane to one side,

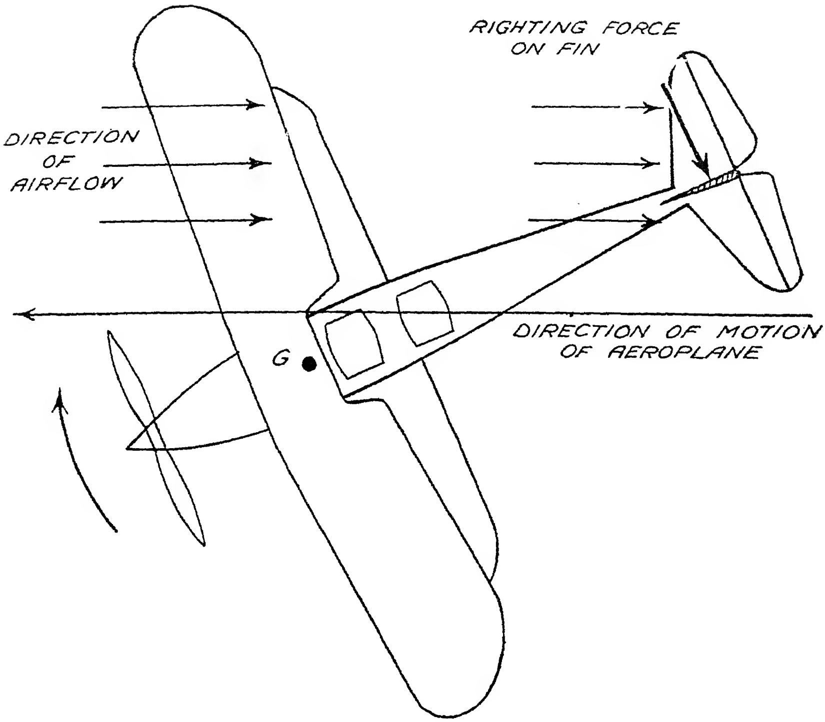


Fig. 9.—DIRECTIONAL STABILITY.

A vertical fin has been fitted on the tail. If a gust of wind deflects the nose of the aeroplane to one side a righting force is now introduced which tends to turn the nose back into wind.

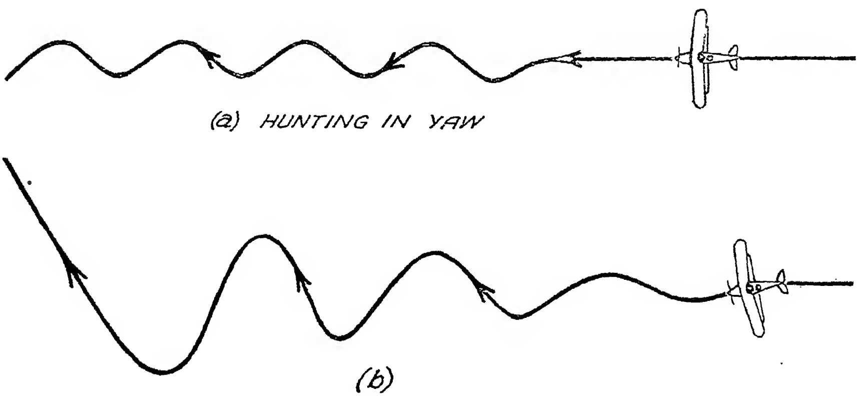


Fig. 10.—DYNAMIC INSTABILITY.

Although statically stable directionally, an aeroplane may, if disturbed, continue to "hunt" regularly (*a*); or to oscillate with increasing amplitude in yaw (*b*). In such event it would be dynamically unstable directionally.

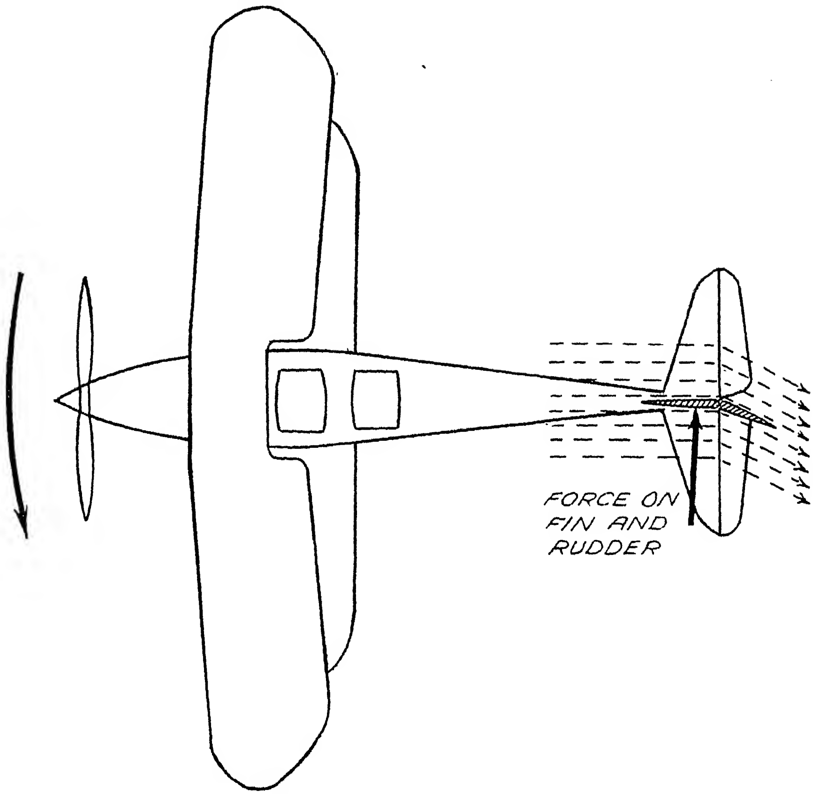


Fig. 11.—RUDDER CONTROL.

When the rudder is put over to port, a force is introduced which tends to turn the nose of the aeroplane to port and *vice versâ.*

say to port, it will proceed "crabwise," skidding or sideslipping to starboard (Fig. 8).

There is no obvious reason why it should either turn further to port or turn back into wind.

As viewed in plan, the aeroplane might be in what is called a *neutrally* stable state of motion, like the neutrally stable state of rest of a ball on a billiard table, which, if displaced slightly, stays at the spot to which it is moved.

A vertical fin is erected on the tail. If the nose goes to one side now the airstream strikes the tail fin on the other side and, acting at this considerable distance aft of the centre of gravity, tends to turn the nose back into wind (Fig. 9). The aeroplane acts like a weathercock and is now said to be statically stable directionally. Although the aeroplane is turned back into wind by the tail fin, it may overshoot the centre

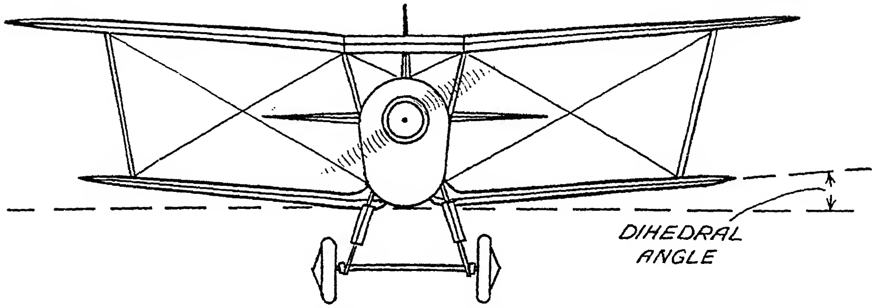


Fig. 12.—LATERAL STABILITY IS NORMALLY SECURED BY GIVING THE WINGS DIHEDRAL ANGLE.

position every time and oscillate or hunt in yaw, in which case it would be dynamically unstable directionally (Fig. 10).

Directional Control

To enable the pilot to turn the nose to port or starboard at will, a hinged control surface or rudder is fitted to the back of the tail fin and connected with levers and cables to the rudder bar in the pilot's cockpit.

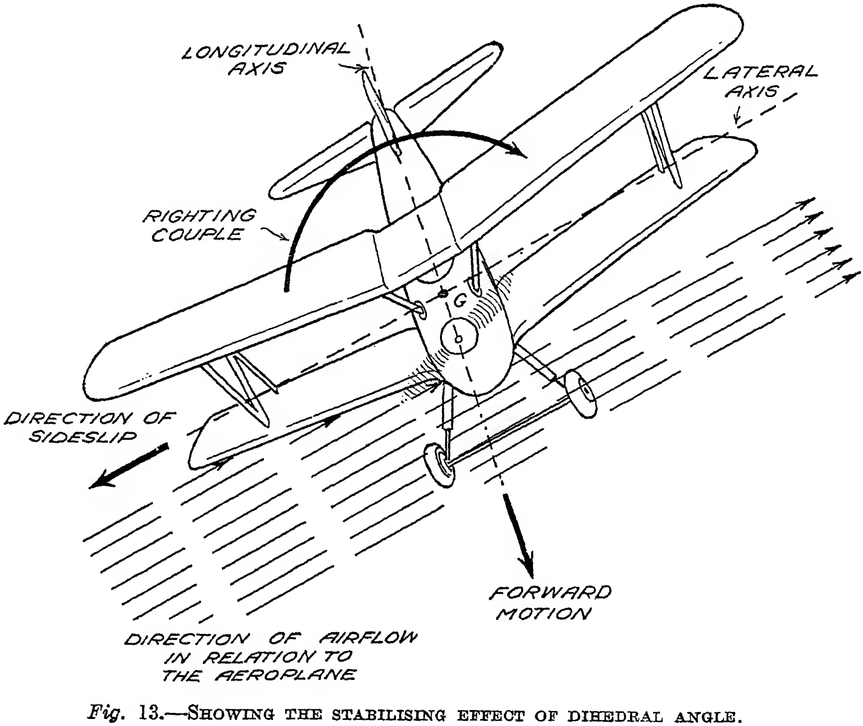


Fig. 13.—SHOWING THE STABILISING EFFECT OF DIHEDRAL ANGLE.

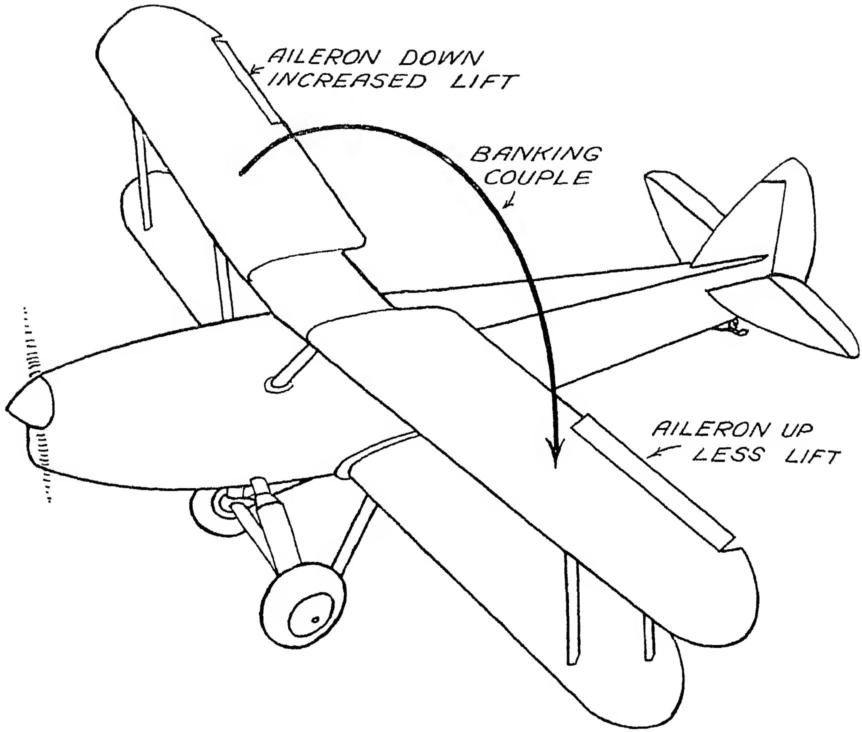


Fig. 14.—LATERAL CONTROL.

When the ailerons on the port wings are put up they reduce the effective angle of attack of the port wing tips, while the down-going ailerons on the starboard wings increase the effective angle of attack of the starboard wing tips. If the wings are unstalled a couple tending to bank the aeroplane to port is thus introduced.

If the pilot puts his rudder over to port, he gives the fin and rudder effective camber with an angle of attack to the airstream which introduces a force tending to turn the nose to port (Fig. 11).

Lateral Stability

If this aeroplane is banked over to port by a bump under the starboard wing, it will proceed to sideslip downwards to port.

Lateral stability is normally secured by giving the wings dihedral angle—that is, fitting them at a slight positive angle to the horizontal as viewed in front elevation (Fig. 12).

When the aeroplane sideslips now, the air strikes the under surface of the depressed wing at a greater angle of attack than it does the elevated wing. So long as the depressed wing remains unstalled, the lift of the depressed wing is thus increased and a righting moment is introduced which tends to put the aeroplane back on an even keel laterally (Fig. 13). In other words, the aeroplane is now statically stable laterally.

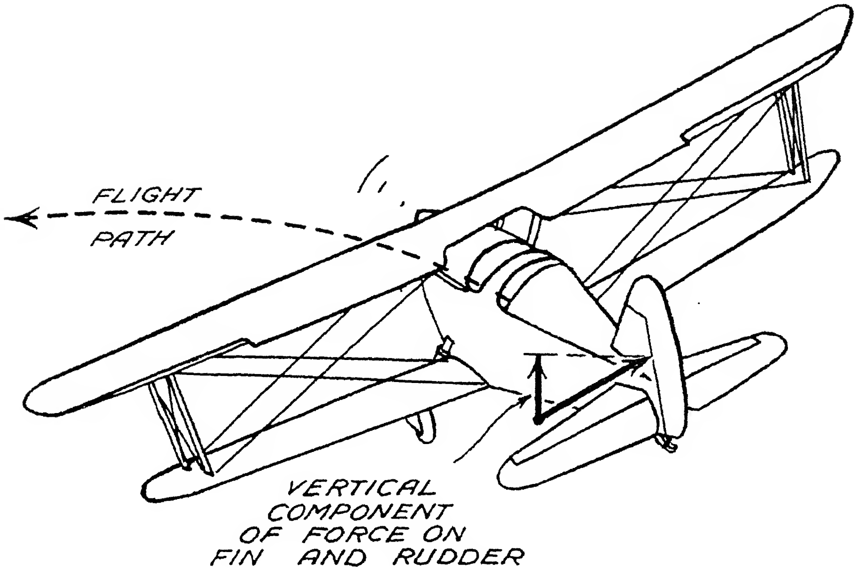


Fig. 15.—Entering a turn.

As the aeroplane banks over on entering a turn, the fin and rudder become inclined to the vertical and the vertical component of the air force on the fin and rudder tends to put the nose down. The pilot must correct for this by pulling his elevator up slightly.

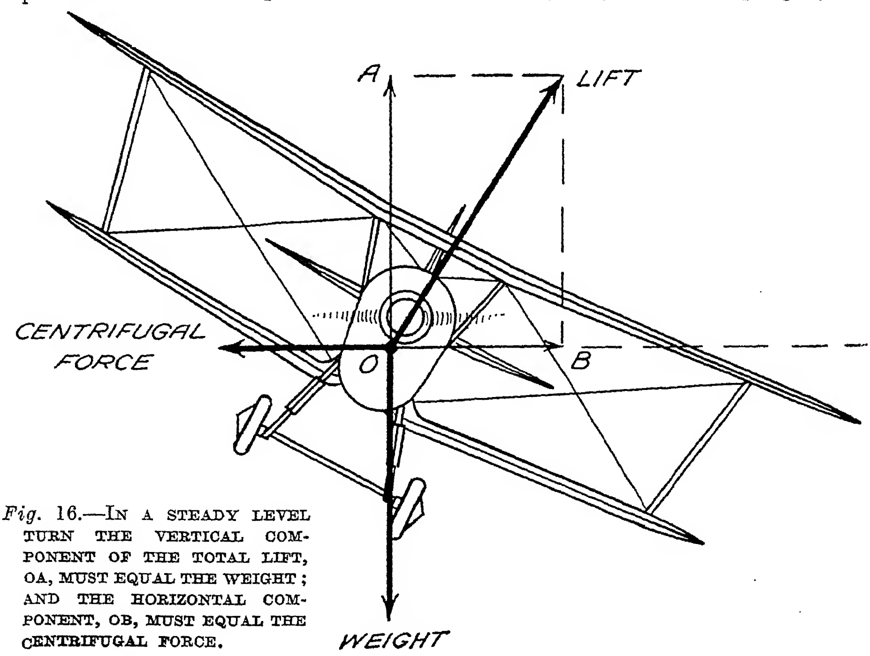


Fig. 16.—In a steady level turn the vertical component of the total lift, OA, must equal the weight; and the horizontal component, OB, must equal the centrifugal force.

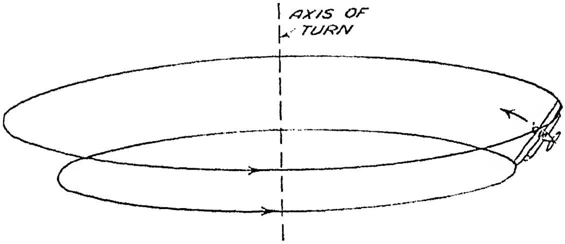


Fig. 17.—IN A CORRECTLY BANKED LEVEL TURN THE ANGLE OF ATTACK OF BOTH WINGS IS THE SAME.

The inner depressed wing tips travel round the vertical axis of the turn in a smaller circle than the outer elevated wing tips, their velocity is therefore less and so their lift is less. Hence the tendency to overbank in a level turn.

It may, however, be dynamically unstable laterally, and continue to oscillate in roll about its longitudinal axis.

Lateral Control

To enable the pilot to bank on turns or for any other reason, such as to sideslip, hinged control surfaces or ailerons are fitted on the trailing edges of the wing tips and connected with levers and cables to each other and to the pilot's control column.

When the pilot moves the ailerons on his port wings up they reduce the camber and effective angle of attack of their wing tips. If the wings are unstalled this reduces their lift ; at the same time the downward moving ailerons on the starboard wing tips increase their camber, angle of attack and this increases their lift. A couple is thus introduced, tending to roll or bank the aeroplane to port (Fig. 14).

Level Turns—Interaction of Controls

When the pilot turns the nose of his aeroplane to one side with his rudder, it commences to skid round, sideslipping outwards. If the wings are unstalled, the sideslip, as a result of the dihedral angle at which the wings are set, introduces a rolling couple tending to bank the aeroplane automatically in the right direction for the turn. It may, however, bank over too much, and proceed to sideslip inwards or bank over too little and continue to sideslip outwards. By using his ailerons the pilot can bank correctly and turn comfortably without sideslipping.

If the pilot uses his ailerons only and banks to one side, say to port, the aeroplane will commence to sideslip downwards to port. The weather-cock effect of the tail fin and rudder will then tend to turn the nose downwards and to port.

It is thus obvious that in order to enter a turn correctly, without side-slipping, the pilot must put on the correct relative amounts of both rudder and aileron.

As the aeroplane banks over, the fin and rudder cease to be vertical and the vertical component of the resultant air force on the fin and rudder tends to turn the nose down (Fig. 15). To prevent the nose from dropping the pilot must pull his elevator up a little and introduce an equal downward force on the tailplane and elevator.

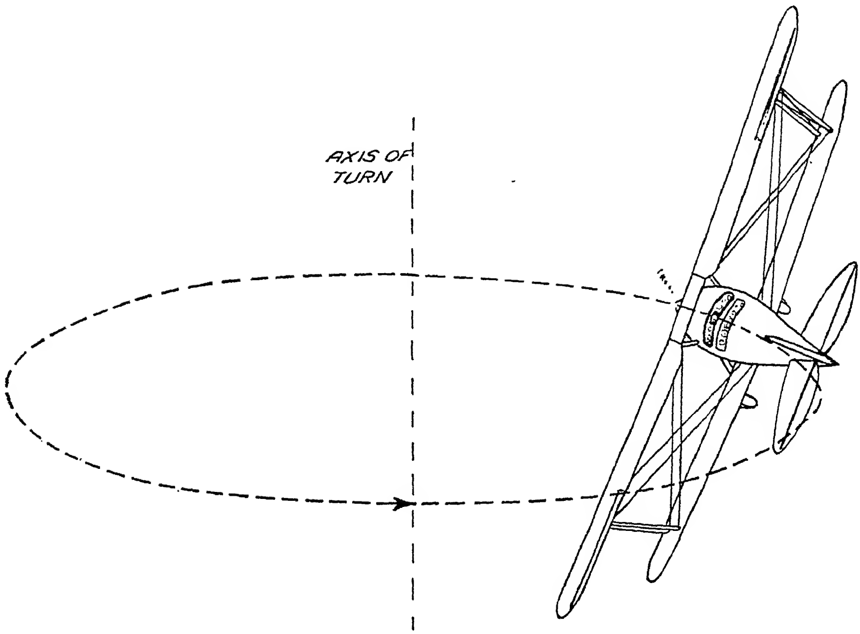


Fig. 18.—IN A "VERTICAL BANK" THE FIN AND RUDDER ARE NEARLY HORIZONTAL AND THE TAILPLANE AND ELEVATOR ARE NEARLY VERTICAL.

Forces in a Level Turn

The total lift on an aeroplane in a level turn acts at an angle to the vertical (Fig. 16).

To turn steadily in a circle at constant speed, the horizontal component of the total lift, which acts inwards, must equal the centrifugal force on the aeroplane in the same way as when a stone is whirled round on the end of a string, the string must exert the force required to prevent the stone from flying off at a tangent.

The vertical component of the total lift must equal the all-up weight in a correctly banked level turn, so the total lift must be greater than in horizontal flight on an even keel. To turn correctly without losing height the pilot must, therefore, either increase the engine r.p.m. as he enters the turn and fly a little faster at the same angle of attack, or pull his elevator further back in order to turn the nose up slightly and increase the angle of attack of the wings. In the latter event the drag of the wings will also be increased and he will therefore require to increase the r.p.m. of the engine in order to maintain the speed at which he commenced to turn. He must also, of course, take off the extra bit of elevator movement after it has given the wings their correct angle of attack, otherwise the angle of attack would continue to increase.

In a level turn the inner depressed wing tips are moving round the vertical axis of the turn in a smaller circle than the outer wing tips (Fig. 17). The inner wing tips are therefore moving more slowly through the air and the lift of the inner wings is then less than that of the outer wings. This is why an aeroplane tends to overbank in a level turn and why the pilot must ease off and in some cases reverse his ailerons in order not to overbank.

Wing Loading and Load Factor

As in cornering a car, the faster an aeroplane is travelling and the sharper the turn, the steeper the bank required to turn correctly.

The steeper the bank the greater the lift must be for its vertical component to equal the weight of the aeroplane and so maintain height. The air pressure per square foot on the wings, the wing loading as it is called, is, therefore, considerably greater in tight turns than in horizontal flight on an even keel. It may become five or more times the normal loading in straight flight. If the wings are designed to carry, say, seven times the loading required to support the weight in horizontal flight on an even keel they are said to have a " load factor " of seven and would fail if the loading were increased beyond that figure.

Rudder and Elevator Controls in Steeply Banked Turns

The steeper the bank the more the fin and rudder become inclined to the vertical. In what is called a " vertical bank," the fin and rudder are nearly horizontal and the tailplane and elevator are nearly vertical (Fig. 18).

The steeper the bank required for the turn the more the elevator must, therefore, be pulled up to keep the aeroplane turning, while the rudder must be reversed to keep the nose from dropping. It is sometimes incorrectly stated that the rudder becomes the elevator and *vice versâ* in a vertical bank.

PRINCIPLES OF FLIGHT

SECTION IV

CONTROLS

Balanced Controls

In order that the pilot should not become over-fatigued on long flights and in bumpy weather, the control surfaces are often partially balanced.

One method is to place a portion of the control surface in front of its hinge line, so that when the control is moved the air striking the front portion assists the pilot to move the control. A horn balanced rudder is shown in Fig. 1. Note the position of the hinge line and the horn or portion in front of it. A similarly balanced elevator is shown in Fig. 2, with its leading edge in front of its hinge line.

Care must be taken not to overbalance controls, otherwise the pilot loses "feel" and, furthermore, controls overbalanced in the above manner would be unstable in their neutral position. As we have already seen, the resultant force on an aerofoil normally acts well forward and moves farther forward as its angle of attack increases. If the centre of pressure of the control surface moved forward of the hinge line, the control surface would tend to blow right over (Fig. 3). Much more than half of the control surface must therefore lie behind its hinge line.

Another method of lightening controls is by fitting balance tabs. A moveable surface or balance tab is hinged to the trailing edge of the elevator and connected to a fixed point on the tail plane by a lever and rod, so that when the pilot moves the elevator, the balance tab moves over in the opposite direction. The resulting air

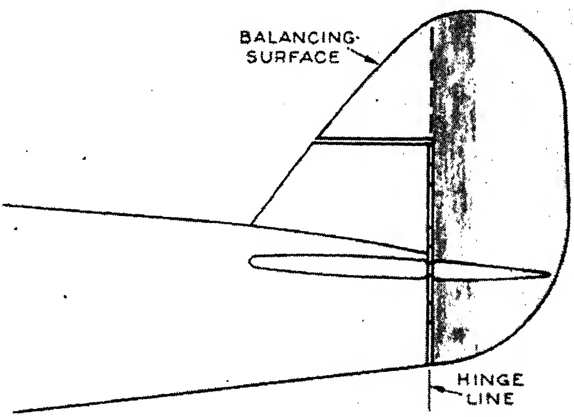


Fig. 1.—A HORN BALANCED RUDDER.

When the pilot moves the rudder the air striking the horn or portion in front of the hinge line assists him in moving it further.

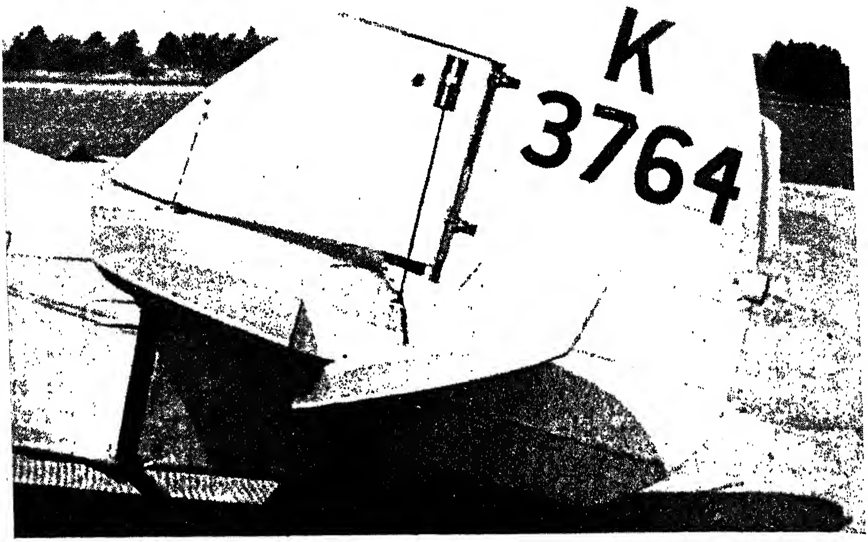


Fig. 2 (*above*).—A HORN BALANCED RUDDER AND ELEVATOR.

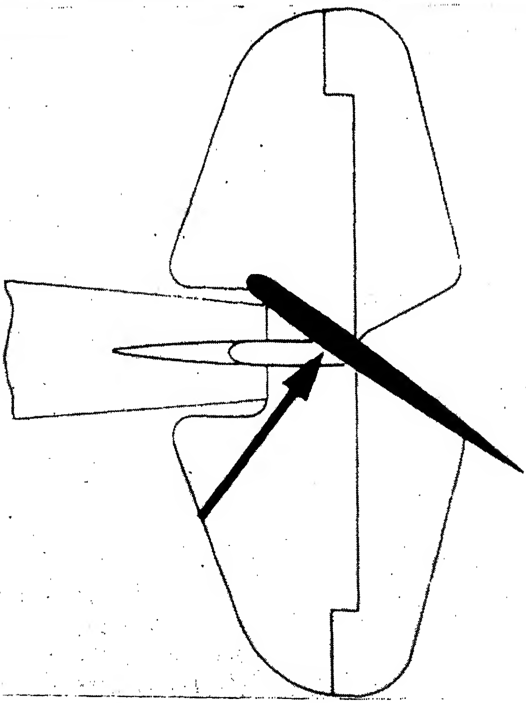


Fig. 3 (*left*).—AN OVER-BALANCED RUDDER.

If the centre of pressure of the control surface moves forward of the hinge line the control surface is over-balanced and will tend to blow right over.

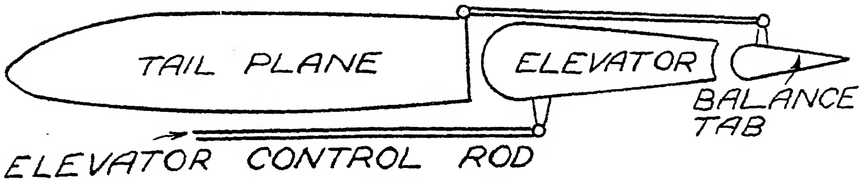


Fig. 4A.

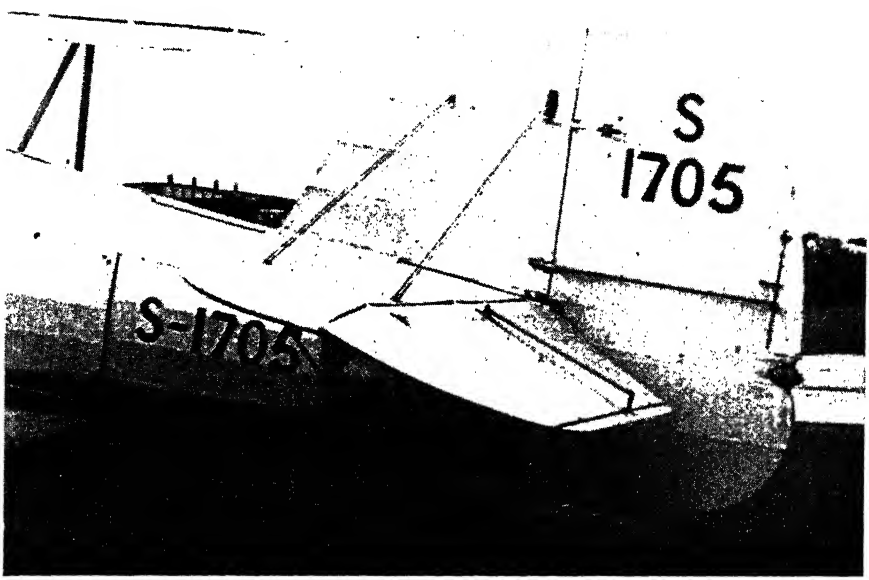


Fig. 4B.

Figs. 4A and 4B.—A BALANCE TAB FITTED ON AN ELEVATOR.

The pilot operates the elevator directly and movement of the balance tab is dependent upon the movement of the elevator. The lever on the tab is pin-jointed to a rod which in turn is pin-jointed to a fixed point on the tail plane. The balance tab therefore moves in the opposite direction to the elevator and the air pressure on the tab then assists the pilot to move the elevator further. In Fig. 4B the rod from the balance tab is attached to an extension from the fixed portion of one of the elevator hinge points.

pressure on the balance tab assists the pilot to move the elevator in the desired direction (Fig. 4, *a* and *b*).

Fig. 5 shows a similarly lightened rudder. The rod from the balance tab lever is attached to a fixed point on the fin, so that on moving the rudder the balance tab on the trailing edge moves in the opposite direction.

Fig. 6 is an example of a similarly lightened aileron working on exactly the same principles.

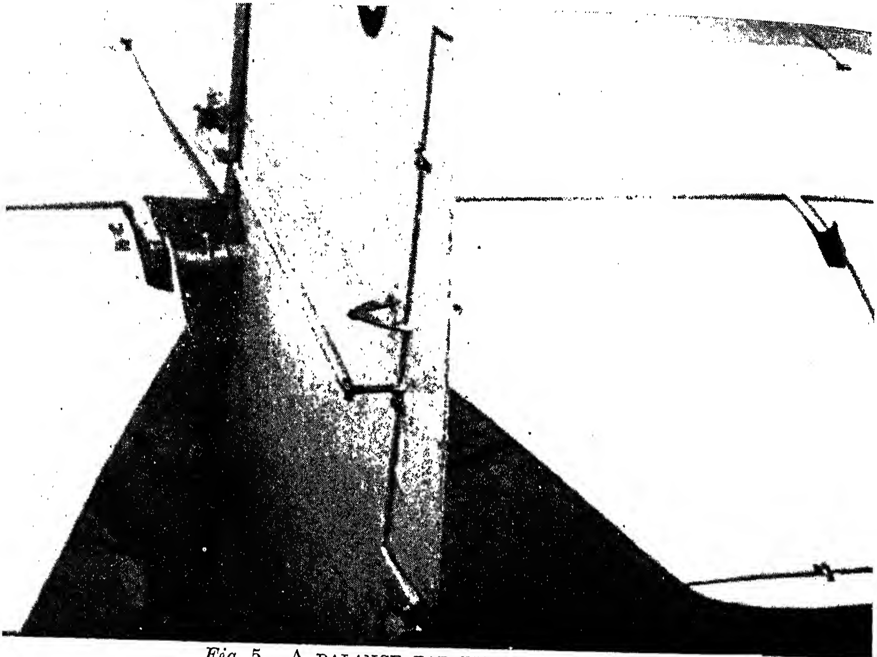


Fig. 5.—A BALANCE TAB FITTED ON A RUDDER.

The rod from the balance tab is pin-jointed to an arm rigidly attached to the fin. When the pilot moves the rudder to one side the balance tab moves in the opposite direction. The air pressure on the balance tab then assists the pilot to move the rudder further over, thus lightening the rudder control. Another view is shown in Fig. 4B.

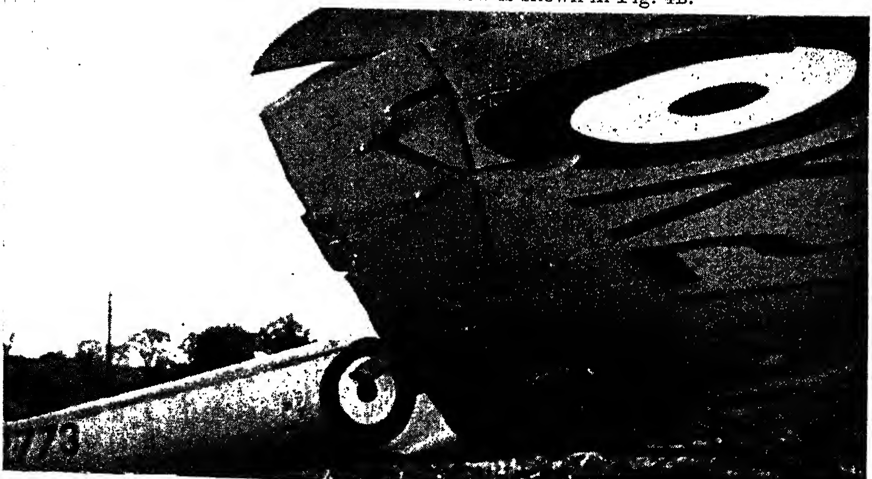


Fig. 6.—A BALANCE TAB FITTED ON AN AILERON.

The rod from the balance tab is pin-jointed to an extension from the fixed portion of one of the aileron hinge points. When the pilot moves the aileron down the balance tab moves up and *vice versâ.*

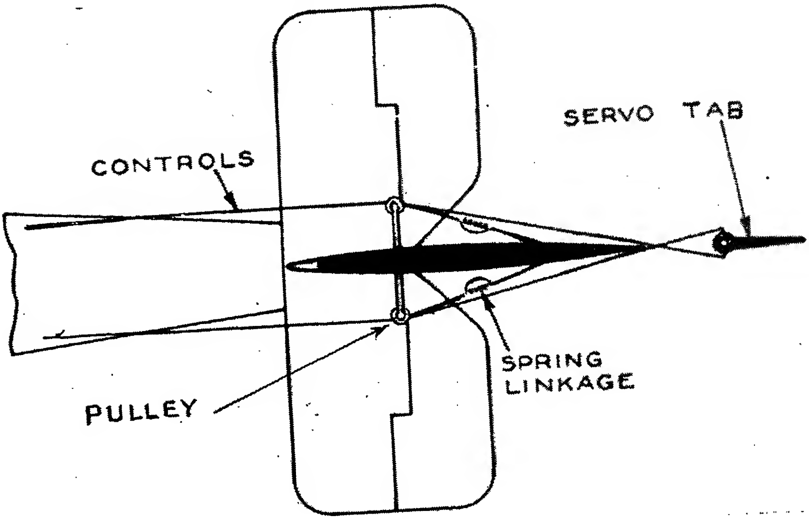
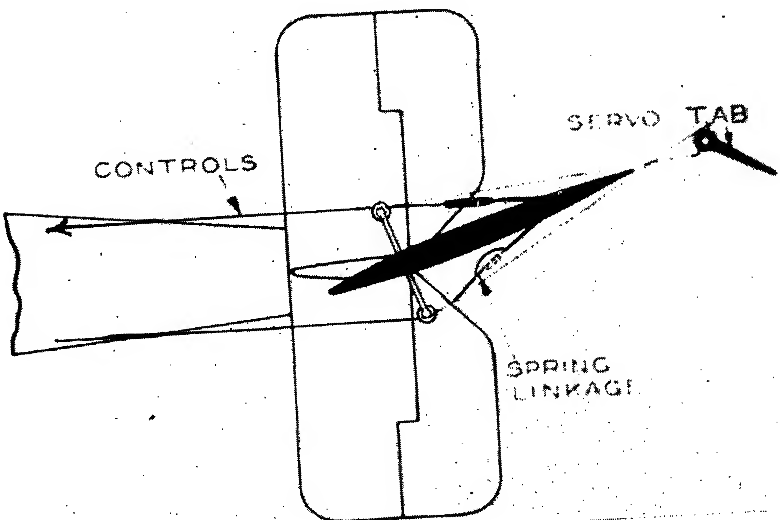

SERVO TAB
CONTROLS
SPRING
LINKAGE
PULLEY

Fig. 7A.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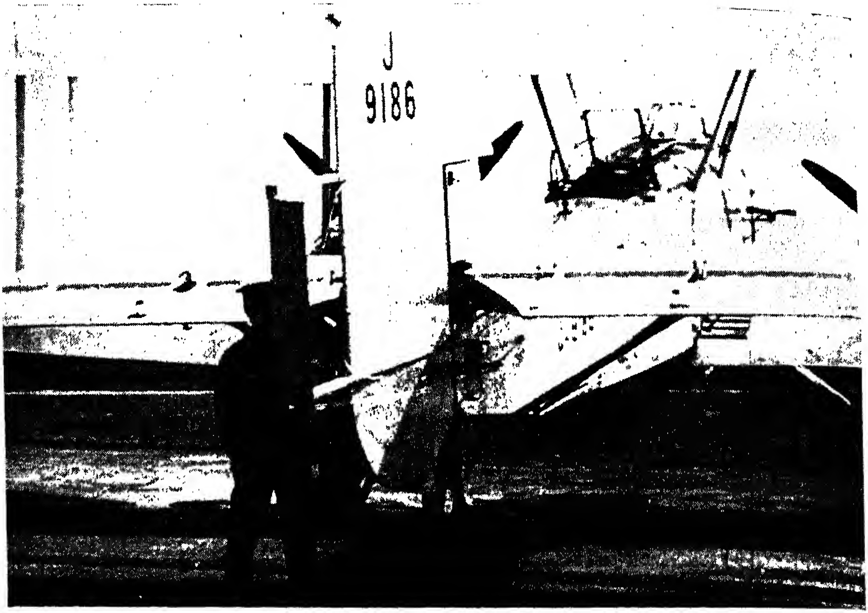


Fig. 7C.

Figs. 7A, 7B and 7C.—AN EARLY FORM OF SERVO CONTROL APPLIED TO A RUDDER. When the pilot operates the rudder control in his cockpit the first effect is to move the servo tab in the opposite direction and thus introduce a force tending to move the rudder in the desired direction. On application of further rudder control the spring linkage, shown clearly in (*a*) and (*b*), extends and the pilot ultimately operates the rudder directly. From this stage onwards the servo tab acts as a balance tab or lightening device.

Servo Controls

Servo controls consist of a hinged surface or servo tab, attached aft of the main control surface, but so connected that the pilot moves the servo tab in the opposite direction to that in which he wishes to move the main control. The leverage of the resulting air pressure on the servo tab about the hinge line of the main control then proceeds to move the main control surface in the desired direction (Fig. 7, *a*, *b* and *c*).

When the pilot puts on still more rudder he extends a spring linkage until, when fully extended, he pulls directly on the rudder. From this stage onwards the servo tab acts as a balance tab or a lightening device, assisting the pilot to move the rudder farther over.

Fig. 8, *a*, *b* and *c*, show a servo controlled elevator with a servo tab hinged on its trailing edge. The servo tab is moved first and the air pressure on it proceeds to move the elevator over in the opposite direction. In this case the spring linkage in the main control is replaced by stops, which enable the pilot to operate his elevator directly after having moved the servo tab over a certain amount.

Fig. 9 gives an example of the same principle applied to a rudder.

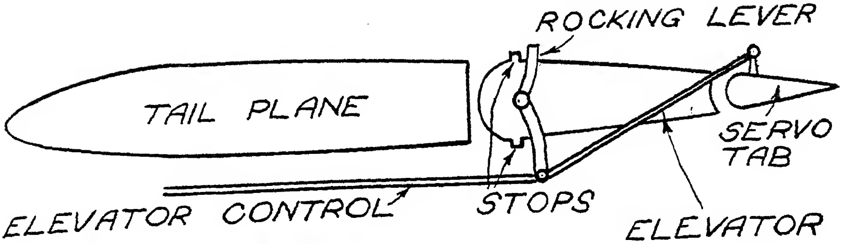


Fig. 8A.

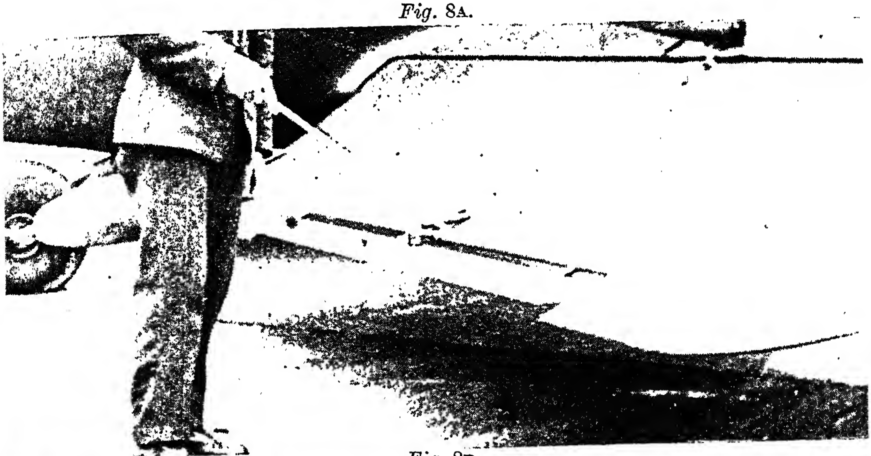


Fig. 8B.

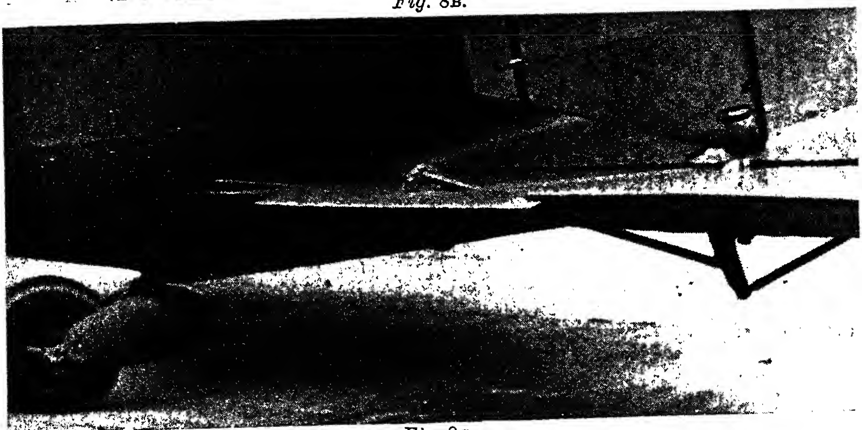


Fig. 8C.

Figs. 8A, 8B and 8C.—A SERVO TAB FITTED ON AN ELEVATOR.

The servo tab is directly operated by the pilot's control column in the opposite sense to that in which he wishes to move his elevator. The air pressure on the servo tab proceeds, in turn, to move the elevator in the desired direction. When the pilot moves his control column far enough, the rocking lever comes up against one of the stops shown in (*a*), and he then operates the elevator directly. From then on the servo tab acts as a balance tab or lightening device.

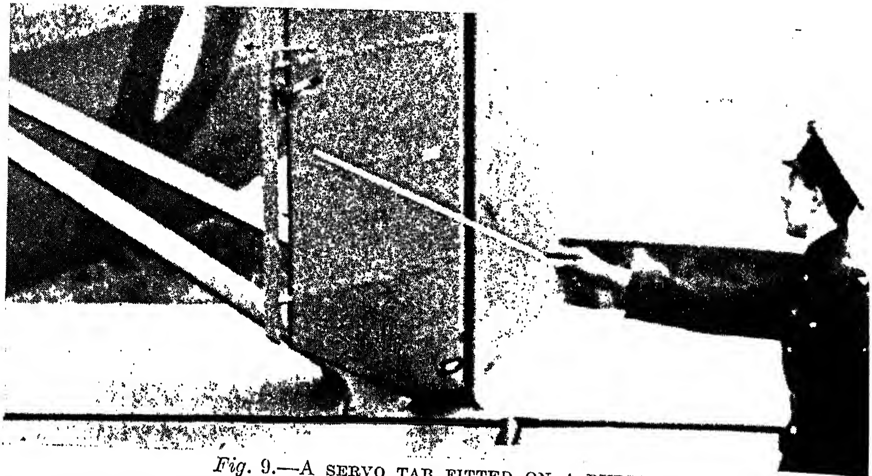


Fig. 9.—A SERVO TAB FITTED ON A RUDDER.

The servo tab is directly operated by the pilot in the first instance. It produces a force which, in turn, proceeds to move the rudder in the opposite direction. When the pilot puts his rudder bar over far enough, he operates the rudder directly and the servo tab then acts as a balance tab or lightening device.

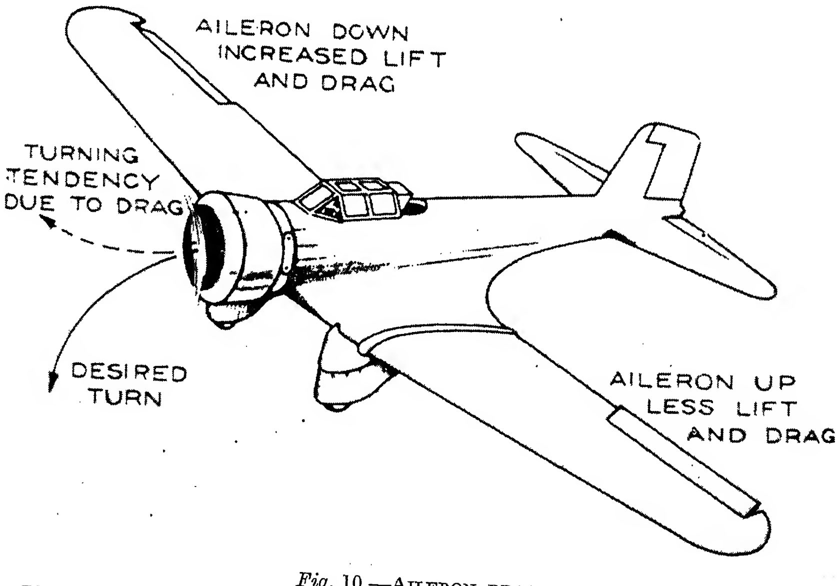


Fig. 10.—AILERON DRAG.

The aileron which is put down to increase the lift and so elevate its wing tip, normally increases the drag of its wing tip. Meanwhile the aileron which is moved up on the other wing tip to reduce its lift and so depress that wing tip, also reduces its drag because the relatively slight upward movement of the aileron reduces the effective angle of attack of its wing tip. A couple tending to yaw the aeroplane in the wrong direction for the desired turn is thus introduced.

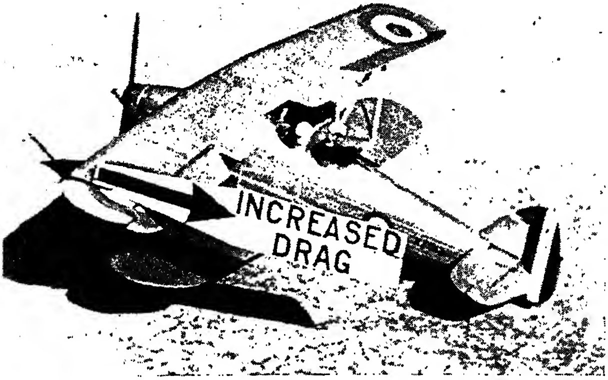


Fig. 11 (*left*).—AILERON DRAG.

Aileron drag is made use of in taxying. The downgoing aileron increases the effective angle of attack and the drag of its wing tip. The port aileron is therefore put down in turning to port on the ground, and *vice versâ*.

Aileron Drag

In entering a turn to port, in normal unstalled flight, the pilot pulls the starboard ailerons down. This increases the virtual camber and

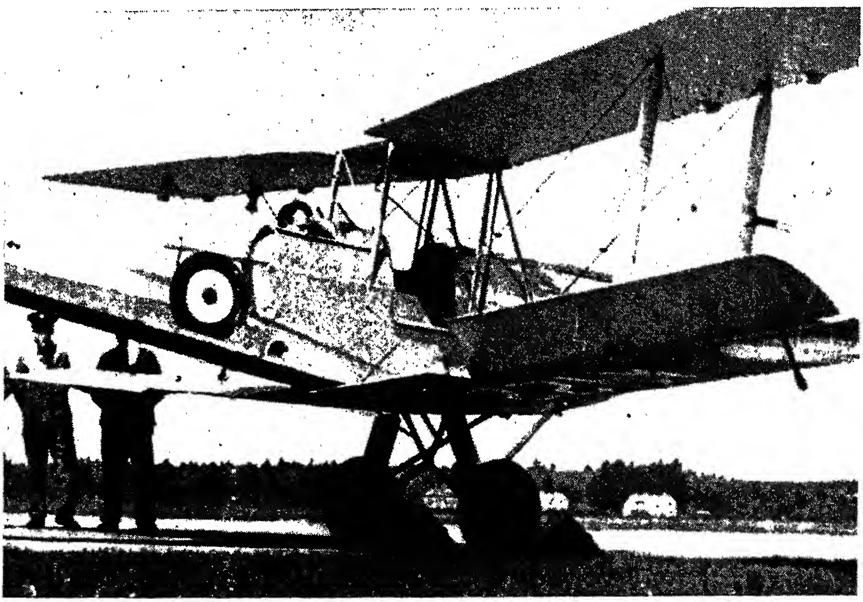
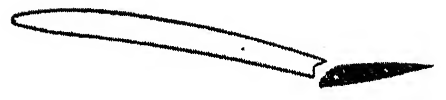


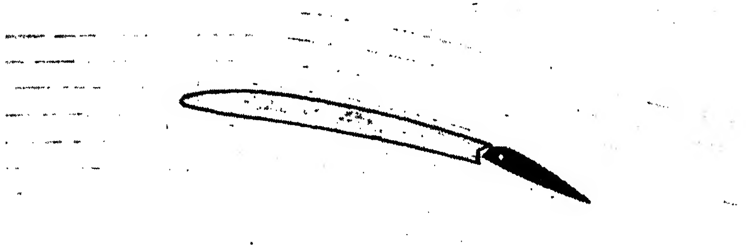
Fig. 12.—REDUCTION OF AILERON DRAG—DIFFERENTIAL AILERONS.

The ailerons are connected differentially so that the upward moving aileron moves up much more than the downward moving aileron moves down. This tends to increase the drag of the depressed wing tip and minimise the drag of the raised wing tip, and thus introduces a yawing couple in the right direction for the desired turn.



FRISE AILERON UP
TURBULENT AIRFLOW

Fig. 13A



FRISE AILERON DOWN
SMOOTH AIRFLOW

Fig. 13B.

13A and 13B.—REDUCTION OF AILERON DRAG—FRISE AILERONS.

(*a*) The nose of the aileron which is put up in order to reduce the lift and so depress its wing tip, projects below the lower surface of the wing, thus increasing the drag of this wing tip and so tending to yaw the aeroplane in the right direction for the intended turn.

(*b*) The aileron on the other wing tip which is put down to increase the lift and raise that wing tip, preserves continuity of surface with the main plane and minimises the undesirable drag in the wrong direction for the turn.

angle of attack, thereby increasing the lift of the starboard wing tips and also their drag. The upward moving port ailerons reduce the virtual camber, angle of attack, lift and drag of the port wing tips. In addition to the rolling couple, another couple is thus introduced which tends to turn the nose to starboard, the wrong direction for the desired turn (Fig. 10). This is the direct effect of aileron drag. Aileron drag is made use of in taxying. When taxying, the wings are stalled so that the downward moving aileron increases the drag of its wing tip considerably. The port aileron is therefore put down in order to assist an aeroplane to turn to port when taxying on the ground (Fig. 11).

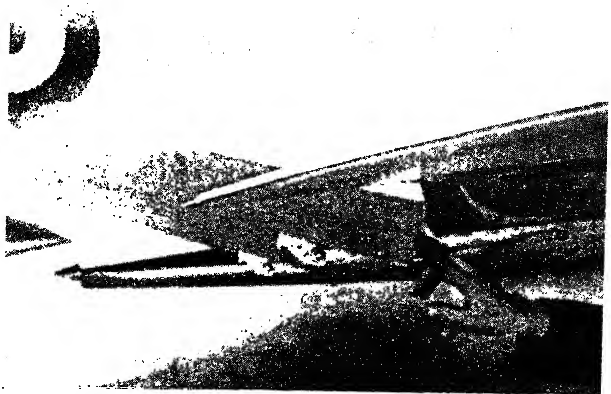


Fig. 14.—AN EXAMPLE OF A FRISE AILERON.
Note the hinge points and how the nose of this upturned aileron protrudes below the lower surface of the wing.

In flight, at normal angles of attack, the pilot can correct the tendency to yaw in the wrong direction with the rudder, but when stalled, not only does the down-going aileron increase the drag of its wing tip considerably by increasing the angle of attack beyond the stalling angle, it also reduces the lift instead of increasing it.

Not only does the aeroplane now tend to yaw in the wrong direction, it actually rolls over in the wrong direction and is quite likely to fall into a spin before the pilot can regain normal control.

Various devices have been developed to overcome these two aileron defects and enable the pilot to retain lateral control when nearly stalled.

The effects desired are that the down-going ailerons should increase the lift and decrease the drag of their wing tips and that the up-going ailerons should decrease the lift and increase the drag of their wing tips. The aeroplane would then tend to yaw in the right direction for the bank and, when stalled, the down-going aileron would still tend to raise its wing as in normal flight.

One method of achieving

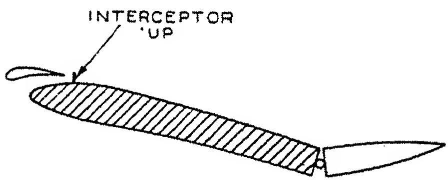


Fig. 15A.

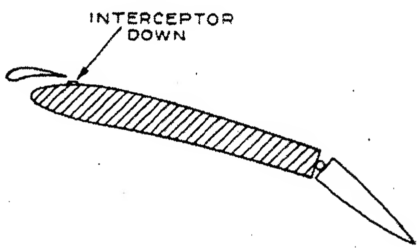


Fig. 15B.

Figs. 15A and 15B.—ANOTHER METHOD OF OVERCOMING THE EFFECTS OF AILERON DRAG.

(*a*) The interceptor moves up and interrupts the airflow under the open Handley Page slat when the aileron behind it is moved up. The drag of this wing tip is therefore increased and its lift is decreased.

(*b*) The interceptor on the other wing tip remains down when its aileron is moved down to increase its lift.

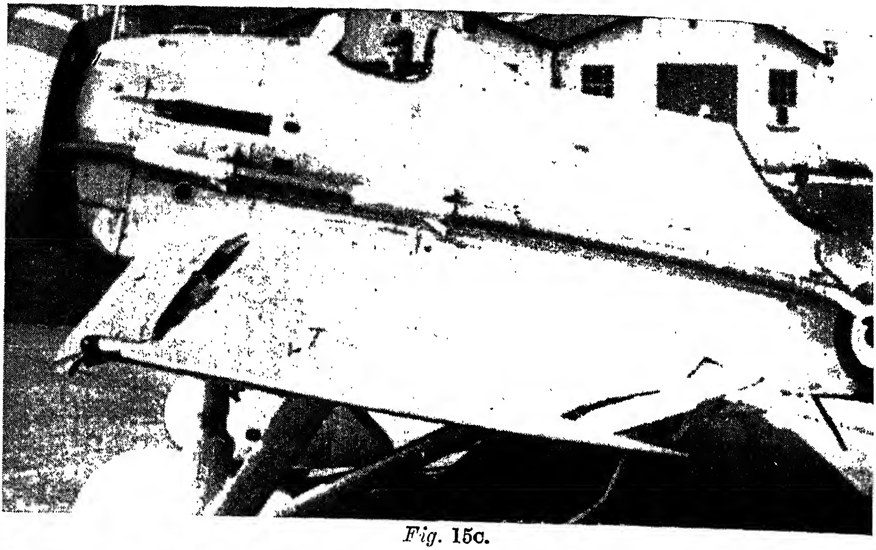


Fig. 15C.

Fig. 15D.

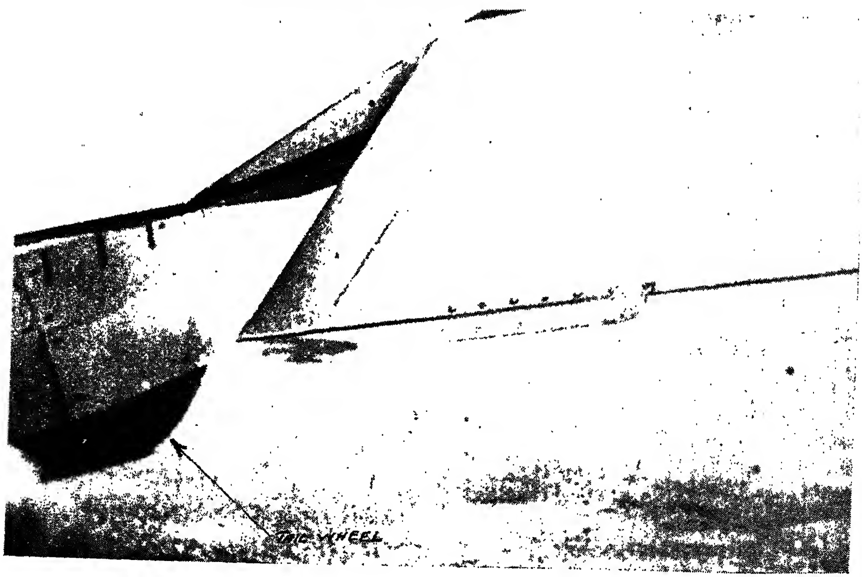
Figs. 15C and 15D.—AN EXAMPLE OF AN INTERCEPTOR FITTED IN CONJUNCTION WITH A HANDLEY PAGE SLAT.

(*c*) The interceptor is interconnected so that it moves up and stalls the portion of the wing tip behind it when its aileron is moved up, thus increasing the drag and further decreasing the lift.

(*d*) Meanwhile the interceptor on the other wing tip remains down when its aileron is moved down to increase the lift. Considerable improvement in lateral control at large angles of attack is thus achieved.

Fig. 16 (*left*).—A TRIMMING TAB ADJUSTABLE ON THE GROUND ONLY, FITTED ON A RUDDER.

Fig. 17 (*below*).—A TRIMMING TAB ADJUSTABLE ON THE GROUND ONLY, FITTED ON AN ELEVATOR.



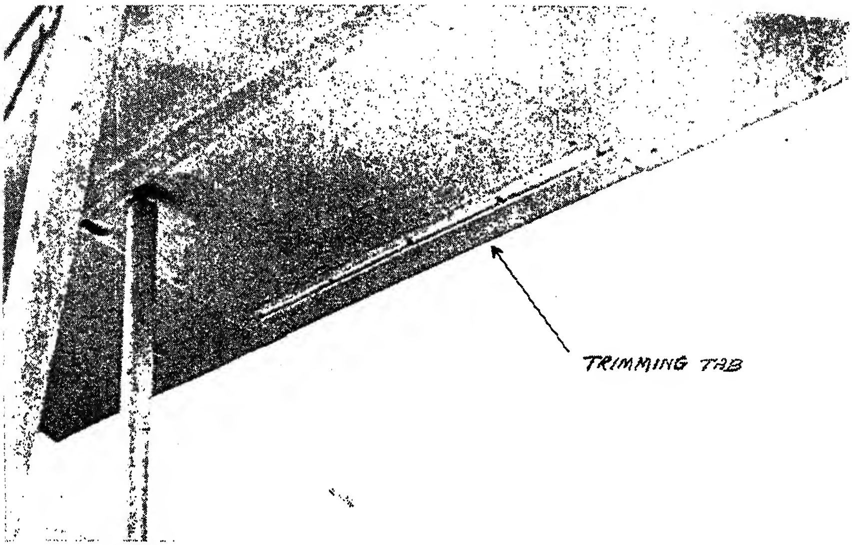


Fig. 18.—AN EXAMPLE OF A TRIMMING TAB ADJUSTABLE ON THE GROUND ONLY, FITTED ON AN AILERON.

this object is to interconnect the ailerons differentially, so that the upward moving aileron moves up through a much larger angle than the downward moving aileron moves down. The upward moving aileron thus induces more drag than the downward moving aileron (Fig. 12).

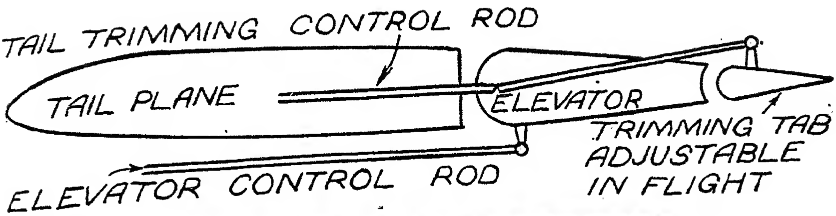
Frise ailerons, which are partially balanced, are so shaped that the down-going aileron preserves continuity of surface with the top surface of the main plane, thus giving minimum drag, while the nose of the up-going aileron protrudes below the lower surface of the main plane, thereby causing turbulence and increasing the drag (Fig. 13, *a* and *b*).

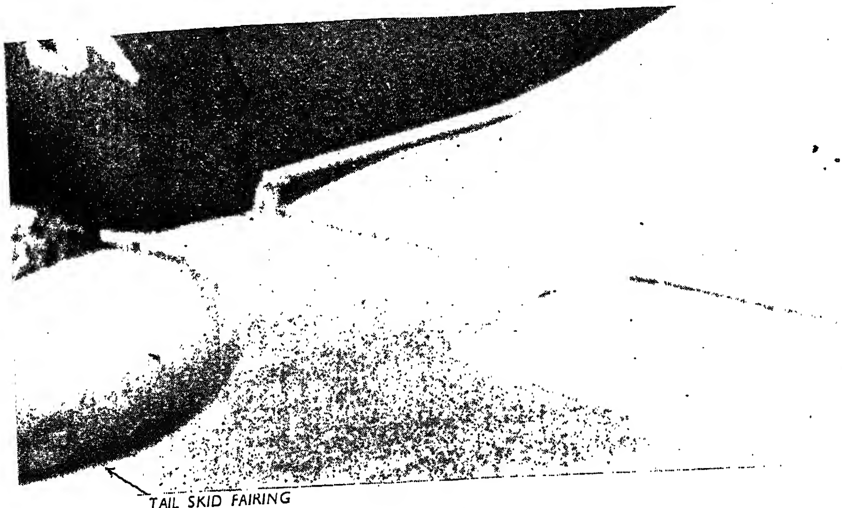
A typical Frise aileron is shown in Fig. 14. Note the position of the hinge line and how the leading edge of the aileron protrudes below the lower surface of the main plane when the aileron is up.

Where automatic Handley Page slats are installed, a narrow plate, called an interceptor, is sometimes fitted, so that it moves up and interrupts or spoils the flow of air under the Handley Page slat when the aileron on that wing moves up. The lift is decreased and the drag increased by disturbing the air flow over the wing on which the aileron is moved up.

Fig. 19.—TRIMMING TABS ON FRISE AILERONS.

If the trimming tab on a Frise aileron is adjusted downwards too far, the aileron may overbalance when it is moved up and its leading edge protrudes below the bottom surface of the wing.





Figs. 20A and 20B.—TAIL TRIMMING GEAR.

An example of a trimming tab adjustable in flight, used as a tail trimming gear.

The interceptor remains down when the aileron is in its neutral and down positions (Fig. 15, *a*, *b*, *c* and *d*).

Trimming Tabs

It is practically impossible to erect high-speed aeroplanes accurately enough on the ground for them to be "in trim" and under comfortable control, when flying at over 200 miles an hour.

Minor rigging errors and structural irregularities, too small to detect on the ground, are found to have large and, in some cases, dangerous effects on trim and control at very high speeds.

Trimming tabs are accordingly fitted along the trailing edges of the control surfaces of high-speed aeroplanes.

Fig. 16 shows one fitted on a rudder, Fig. 17 one on an elevator and Fig. 18 one on an aileron.

Such trimming tabs are adjustable on the ground only and that within fixed limits. They are used to meet the fine adjustments for trim and control, found necessary on air test.

Trimming Tabs on Ailerons

Trimming tabs on ailerons have two effects. They may be used either to lighten the aileron control system as a whole or to obtain lateral trim.

A word of warning is called for when adjusting trimming tabs on Frise ailerons. When the trimming tabs on both ailerons are adjusted downwards they tend to make both ailerons fly up at their trailing edges and so lighten the whole aileron control system. In the case of Frise ailerons this may result in overbalancing when the leading edge of the upward moving aileron protrudes below the bottom surface of the wing (Fig. 19).

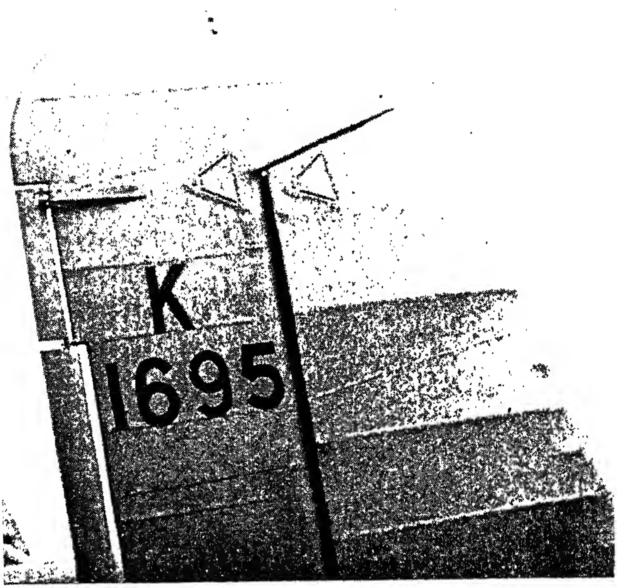


Fig. 21.—RUDDER BIAS GEAR.

The upper tab on this horn balanced rudder is a rudder bias gear. Its angle relative to the rudder can be adjusted in flight. The lower tab is the servo tab shown in Fig. 9.

In order to avoid the risk of over-balancing Frise ailerons, their trimming tabs should therefore only be used for lateral trimming. The trimming tab on the aileron of the wing which is flying low should not normally be rigged down in order to bring that wing up, lest it become overbalanced. The trimming tab on the wing which is flying high should, rather, be rigged up in order to bring that wing down.

Tail Trimming and Rudder Bias Gear

Hinged surfaces or trimming tabs under the pilot's control in the air, are sometimes fitted on the trailing edges of elevators to enable the pilot to put his aeroplane in longitudinal trim for the speed at which he wishes to cruise. An example of such a tail trimming gear is shown in Fig. 20, *a* and *b*.

Similarly fitted on the rudder, a trimming tab enables the pilot to correct for the yawing effect of the airscrew slipstream on the fin and to put his aeroplane in directional trim (Fig. 21).

The pilot's control of such trimming tabs is entirely independent of his normal elevator and rudder controls.

THE ORGANISATION OF AERONAUTICAL RADIO SERVICES

RADIO services for aviation are divided into three main classifications :—

1. Point-to-point service.
2. Meteorological service.
3. Aircraft service.

The point-to-point service exists for the purpose of providing channels for speedy communications between airports concerning the movements of aircraft and details of loads carried. In addition, this service is used for the dissemination of urgent information concerning the state of landing grounds and other factors governing the safety and reliability of air transport.

The Point-to-Point Service

In Europe, the point-to-point service, in common with those other services mentioned above, is provided by mutual arrangement between the various countries and no charge is made for the messages handled, as it is considered that they are vital to the safety of operations. Each principal airport is equipped with a station capable of handling this class of traffic and the frequencies used are as follows :—

257 kcs. (1,167 metres).	Esthonia, Latvia, Lithuania, Poland, Roumania and Germany (Konigsberg).
260 kcs. (1,154 metres).	Albania, Algeria, Bulgaria, Egypt, Spain, Southern France, Greece, Southern Italy, Morocco, Palestine, Syria, Tripoli, Tunis, Turkey and Yugo-Slavia.
264 kcs. (1,136 metres).	Germany (Munich), Austria, Switzerland and Northern France (except Le Bourget).
268 kcs. (1,119 metres).	Germany (except Konigsberg and Munich), Belgium, Denmark, Finland, France (Le Bourget), Great Britain, Hungary, Italy, Netherlands, Czecho-Slovakia, Norway and Sweden.

A table showing the intermediate and short waves for the traffic service can be found in Volume I of *Reglement du Service International des Telecommunications de l'Aeronautique.*

Details of the stations employed on the point-to-point or traffic service can be found in Volume II of *Reglement du Service International des Telecommunications de l'Aeronautique*, which is obtainable from the Secretary, Air Ministry (C.A.2), Ariel House, Strand, W.C.2.

With the increase in the amount of traffic which has to be handled, the above-mentioned frequencies have shown a tendency to become congested, with the result that certain frequencies have been allotted in the high frequency bands for the service and at present tests are being made with a view to standardising frequencies for day and night operation. When these tests have been completed, the medium waves at present in use will be discontinued. A further reason necessitating the relinquishing of medium waves for the aeronautical traffic service lies in the gradual increase in the power of broadcasting stations in the frequency bands adjacent to those allotted to the aeronautical service.

Direct Telegraph Circuits

A further relief to the congestion in the radio channels has been obtained by employing direct telegraph circuits between airports and traffic is transmitted and received by teleprinters, thus providing a written record of all traffic. At present, a large number of airports are thus connected by private lines and this type of communication will increase rapidly.

Codes

In order to accelerate the transmission of messages and to reduce their length to the minimum, the following codes have been introduced :—

(*a*) Two-letter groups denoting place names.

(*b*) Three-letter groups denoting type of load carried and the movements of the aircraft.

In addition, names of companies are usually abbreviated by employing their initials only. The following is an example of a coded message relating to the departure of an aircraft :—

IAL PS
G—AEXZ Smith dep 1300 pap 14 pag 3 pos 9 lbs cop 15 lbs fre 50 lbs.
IAL LO

This message would read as follows :—

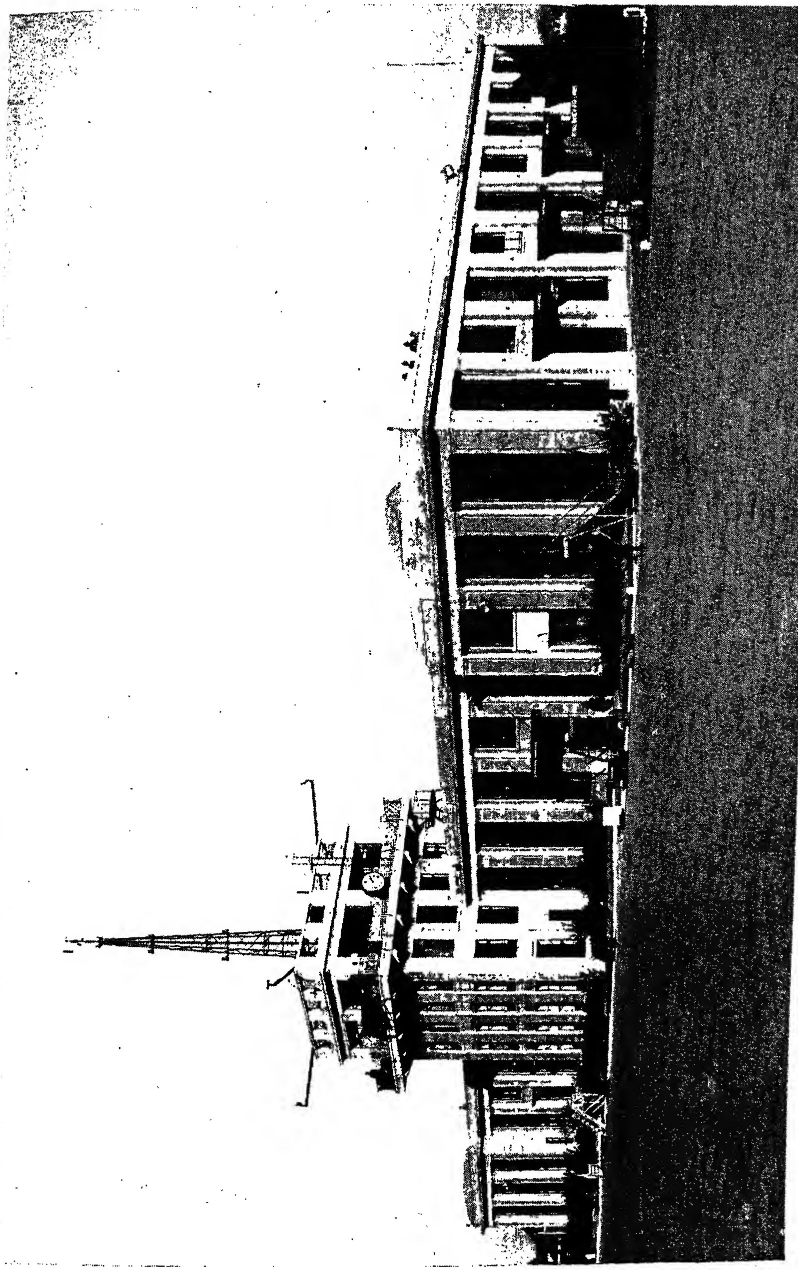
To : Imperial Airways Ltd., Paris.

Aircraft G—AEXZ, Pilot Smith, left Croydon for Paris at 1300 hours, carrying 14 fare-paying passengers, 3 free passengers, 9 lbs. of post, 15 lbs. of postal packages and 50 lbs. of freight.

From : Imperial Airways Ltd., London.

Details of the codes used for traffic messages can be found in Volume II of *Reglement du Service International des Telecommunications de l'Aeronautique.*

In addition to communications relative to movements of aircraft and their loads, the traffic service also handles messages which are necessary for securing regularity and safety. Such messages contain information or orders relative to crews, material or disposition of aircraft. Such



[By courtesy of Marconi's Wireless Telegraph Co. Ltd.

Fig. 1.—THE CONTROL TOWER, CROYDON.

messages may also contain reference to a change of pilots, the despatch of spare parts, alterations to the schedules of regular services, orders regarding landings at airports not regularly used for the purpose of embarking or disembarking passengers.

Meteorological Service

A special radio service has been provided on an international basis in Europe and countries on adjacent continents for the purpose of exchanging regularly information concerning weather conditions. The following frequencies are employed :—

280 kcs. (1,071 metres).	5,830 kcs. (51·46 metres).
284 kcs. (1,056 metres).	6,975 kcs. (43·01 metres).
288 kcs. (1,042 metres).	

Europe and Northern Africa have been divided up into various zones to each of which a separate frequency chosen from those mentioned above has been allotted, and in most of these areas there are six stations broadcasting weather reports every half-hour ; thus, in North-west Europe, it is possible for a pilot at an aerodrome such as Le Bourget to obtain an up-to-the-moment picture of the weather in the area bounded by the West Coast of France, Southern England, Amsterdam, Cologne and Paris, at any time of the day or night.

It may be mentioned here that these reports can be of considerable value to pilots in large transport aircraft where a receiver other than that normally used for communication with the ground is installed. In addition, area collective reports are transmitted by Paris, Berlin, Warsaw, Rome and Bucarest at certain times during the day on a frequency of 276 kcs. (1,087 metres).

These reports, which are sent in code, are intercepted at all the principal meteorological stations throughout Europe and form the basis upon which area forecasts are prepared. These forecasts in turn are made available to pilots and others interested at the various airports throughout Europe.

In order to make this scheme as comprehensive as possible, arrangements have been made for these collective reports to be transmitted on short waves, and reports from the American continent are regularly received three times a day from the radio station at Annapolis. Thus, it is possible for the forecaster to draw a map showing the distribution of pressure over the whole of the Northern Hemisphere, and this chart is issued once daily.

Details of the stations in Europe transmitting coded weather reports half-hourly can be found in Volume II of *Reglement du Service International des Telecommunications de l'Aeronautique*, and the codes used in these transmissions can be found in "Wireless Weather Messages, 1937 (MO.252)."

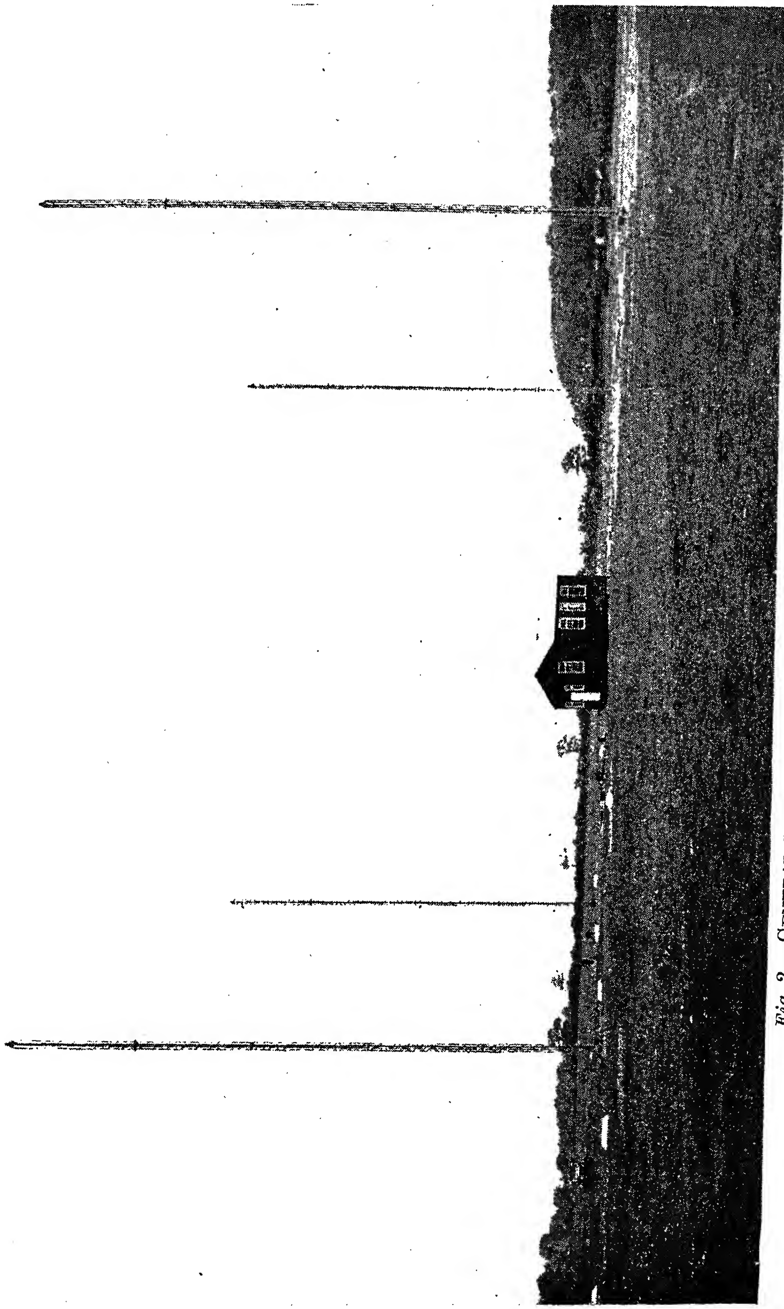


Fig. 2.—GENERAL VIEW OF MARCONI-ADCOCK DIRECTION FINDING STATION.

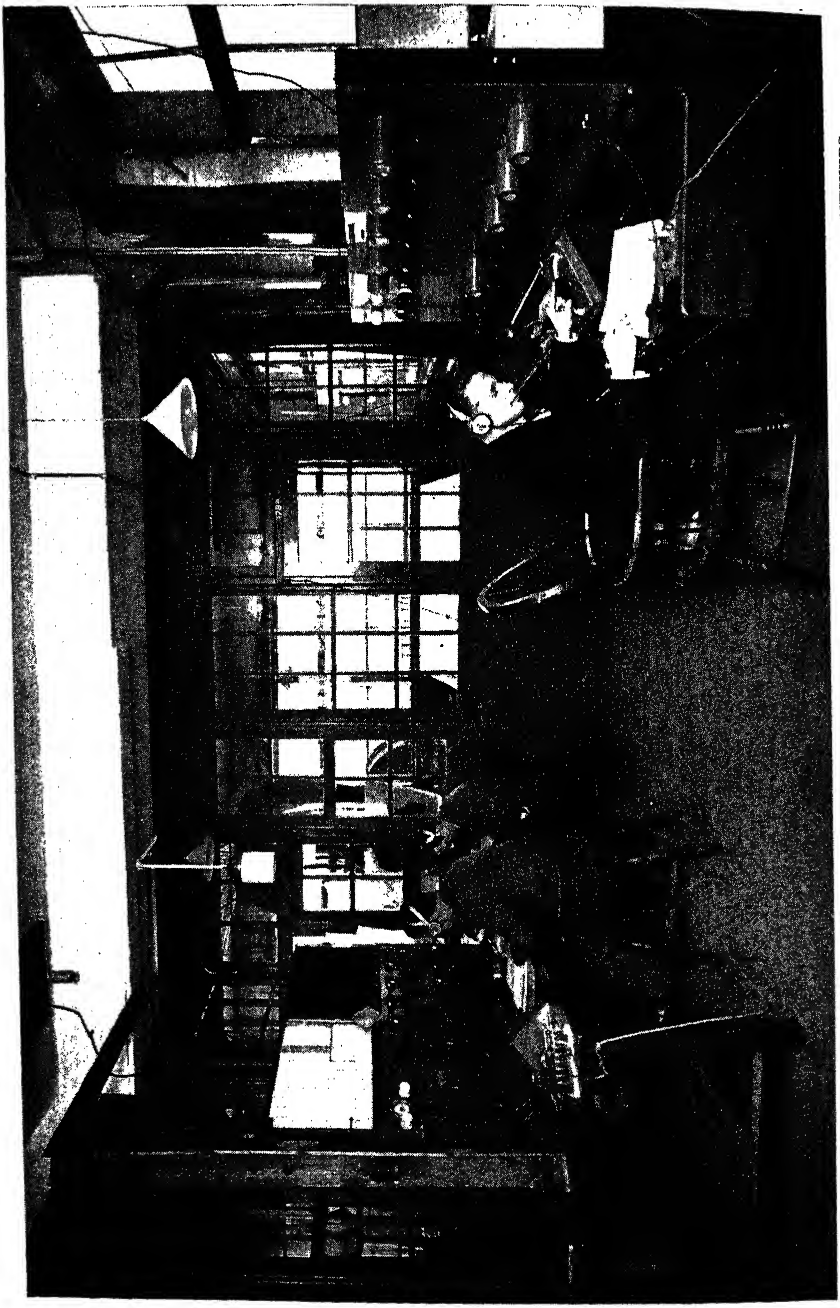


Fig. 3.—CONTROL TOWER AT CROYDON, SHOWING TWO TYPES OF MARCONI DIRECTION FINDING RECEIVERS.

Aircraft Service

The Aircraft Radio Service in Europe is organised on an international basis and a common band of frequencies is used. The following services are provided :—

(A) Normal two-way communication with airports.
(B) Direction finding service.
(C) Radio beacon service.

(A) Normal Two-way Communication with Airports

Each aircraft equipped with radio is required to send such signals as are considered necessary to ensure the safety of its occupants and those on other aircraft flying in the same area. Each main airport radio station has a communication area allotted to it and aircraft in flight must communicate only with the principal station of the area over which it finds itself. It is necessary for this rule to be rigorously observed in order to avoid overloading stations with communications not of primary concern to them.

In addition to the main communication areas, controlled zones have been laid down for most of the important airports, and under certain weather conditions, usually when the visibility is less than 100 metres or the clouds lower than 300 metres, special rules have to be observed by aircraft approaching and passing through these zones preparatory to effecting a landing at the terminal airport.

The imposition of these special rules and the gradual increase in the amount of signalling taking place on the international air routes has necessitated a restriction in the number of messages which aircraft are permitted to send, and in general it may be stated that they are confined to the following :—

(*a*) A signal announcing a departure from an airport in which the starting time and the destination can be stated.
(*b*) Position reports which are made when passing certain places or landmarks which have been specified internationally.
(*c*) Special reports made when flying in bad visibility or cloud. In addition, aircraft flying in these conditions are obliged to report all changes of height and course in order that the ground control may obtain a clear indication of the positions of all aircraft within its area and that it may notify pilots of other aircraft in their vicinity, thus providing a measure of prevention against collisions.

Messages Concerning Safety of Aircraft

In addition to the above categories, there are, of course, messages concerning the safety of the aircraft, and these can be placed under two headings :

(a) Distress messages which are sent by an aircraft when it is in serious danger and requires immediate assistance. The existence of such a state of emergency is, of course, notified by the transmission of the signal SOS when telegraphy is used and the spoken word "Mayday" if telephony is employed.

(b) Urgency messages, which are preceded by the group XXX transmitted three times and followed by the call. This signal indicates that the aircraft has a very urgent message to send concerning the safety of the aircraft itself or a ship or aircraft in sight.

When an aircraft wishes to notify the control station that it is obliged to land, although not in need of immediate assistance, it notifies the fact by transmitting the signal PAN in telegraphy, or the word "Panne" in radio-telephony, and this signal is usually followed by a message giving details of the state of urgency.

The above-mentioned signals, of course, have priority over all other types of message.

(B) Direction Finding Service

In order to provide a check on the navigation of aircraft, when flying in bad weather, direction finding stations are provided which usually work in groups of three, a group being allotted in general to each communication area.

In addition to positions by direction finding obtained from bearings taken by the three stations and plotted on a map at the Area Control Station, the following types of D.F. assistance are available :—

(a) The true bearing of the aircraft from the station addressed.
(b) The true reciprocal of the aircraft from the station addressed.
(c) The magnetic bearing of the aircraft from the station addressed.
(d) The magnetic reciprocal bearing of the aircraft from the station addressed.
(e) The true bearing and distance of the aircraft from the station addressed.
(f) The magnetic reciprocal bearing and distance of the aircraft from the station addressed (this information can only be obtained at present from stations in the United Kingdom).

The majority of the direction finding stations in Europe and adjacent continents are at present of the Bellini-Tosi type, and are not able to give accurate bearings between sunset and sunrise beyond a radius of approximately 30 miles. With the increase in the amount of night flying, however, stations utilising the Adcock system are being erected both in Europe and on the Empire air routes and bearings should then have an accuracy of the order of plus or minus 1°–2°.

(C) Radio Beacon Service

The various systems can be classified under the following headings :—

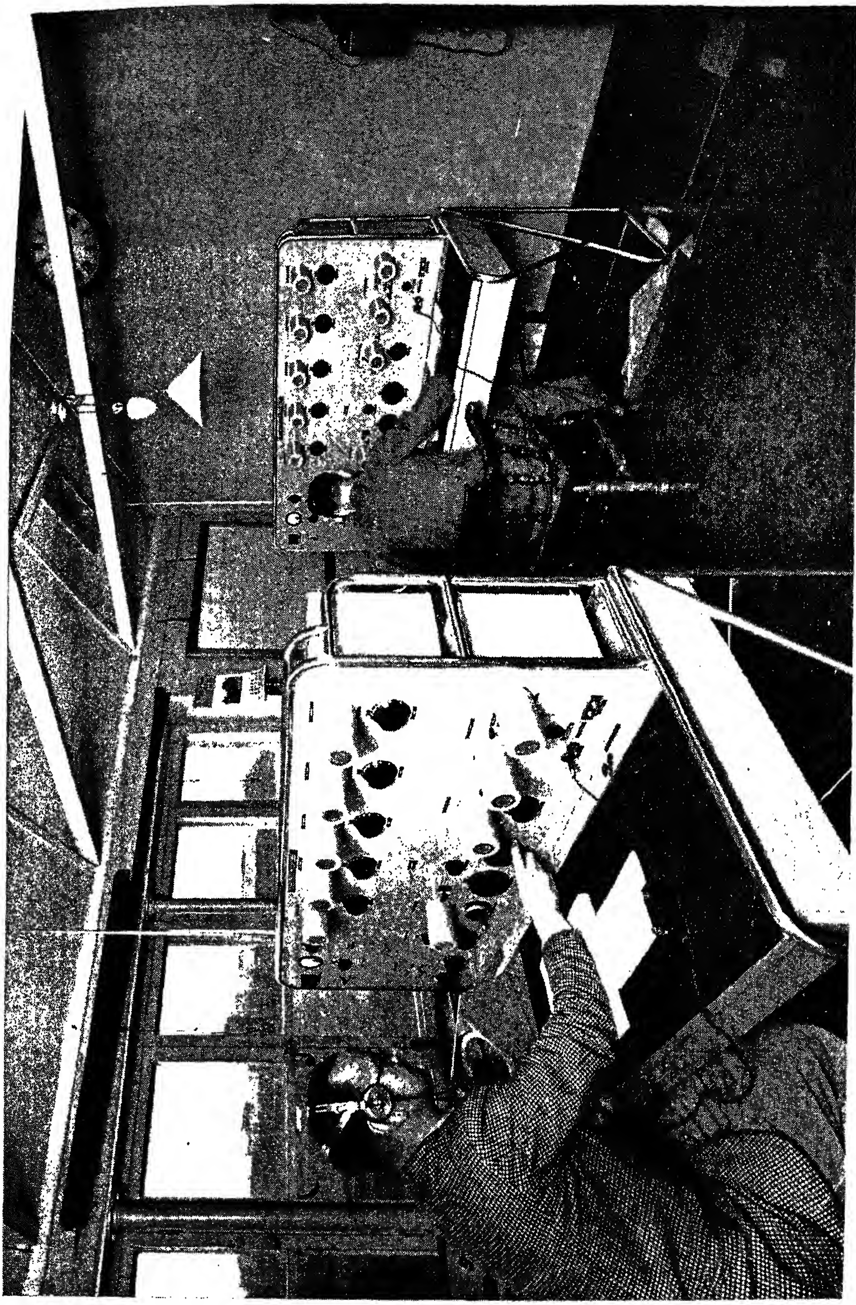


Fig. 4.—TWO MARCONI-ADCOCK D.F.g. 10 DIRECTION FINDERS WORKING OFF A COMMON AERIAL SYSTEM.

(*a*) Omni-directional beacons employing medium waves.
(*b*) Equi-signal beacons employing medium waves, which sub-divide into the following classifications :—
   (i.) Four-course beacons emitting signals received aurally.
   (ii.) Four-course beacons emitting signals received visually.
   (iii.) Two-course beacons emitting signals received aurally.
   (iv.) Two-course beacons emitting signals received visually.
(*c*) Rotating beacons employing medium waves.
(*d*) Two-course beacons employing ultra high frequency waves.
(*e*) Single-course beacons employing ultra high frequency waves.
(*f*) Marker beacons.

Brief descriptions of the above-mentioned types are as follows :—

(*a*) The omni-directional beacon comprises a transmitter emitting a signal consisting of a series of call signs indicating the name of the station, followed by a steady dash. Transmissions from a group of these stations are arranged to permit positions to be obtained by observing the bearings of two or more consecutive emissions. Of course, the bearings are obtained by means of direction finding apparatus fitted to the aircraft.

The organisation set up around the shores of the British Isles for the prime benefit of the mercantile marine presents a good example of the use of radio beacons as described above.

This type of beacon is used for navigational purposes only and does not, of course, lend itself to aerodrome approach and landing work. It has decided advantages, however, on air routes where wireless traffic is congested, for, if a group of such stations is installed, working on frequencies other than those employed for normal communication, it is possible for pilots, by carrying additional D.F. receivers in their aircraft, to obtain positions without sending out requests for such information to the aerodrome ground stations.

(*b*) (i.) This type of beacon comprises a transmitter feeding two loop antennæ in such a way that each antenna is energised alternately with the components of Morse characters which will provide an " interlock." For instance, suppose that the letter A (·—) is transmitted from one antenna and the letter N (—·) from the other, a continuous note will be heard when the aircraft is being flown within a zone on either side of an imaginary line bisecting the angle between each antenna.

This type of beacon is used mainly for navigational purposes, although, provided the power is suitably adjusted, it can be used in conjunction with marker beacons for approach work.

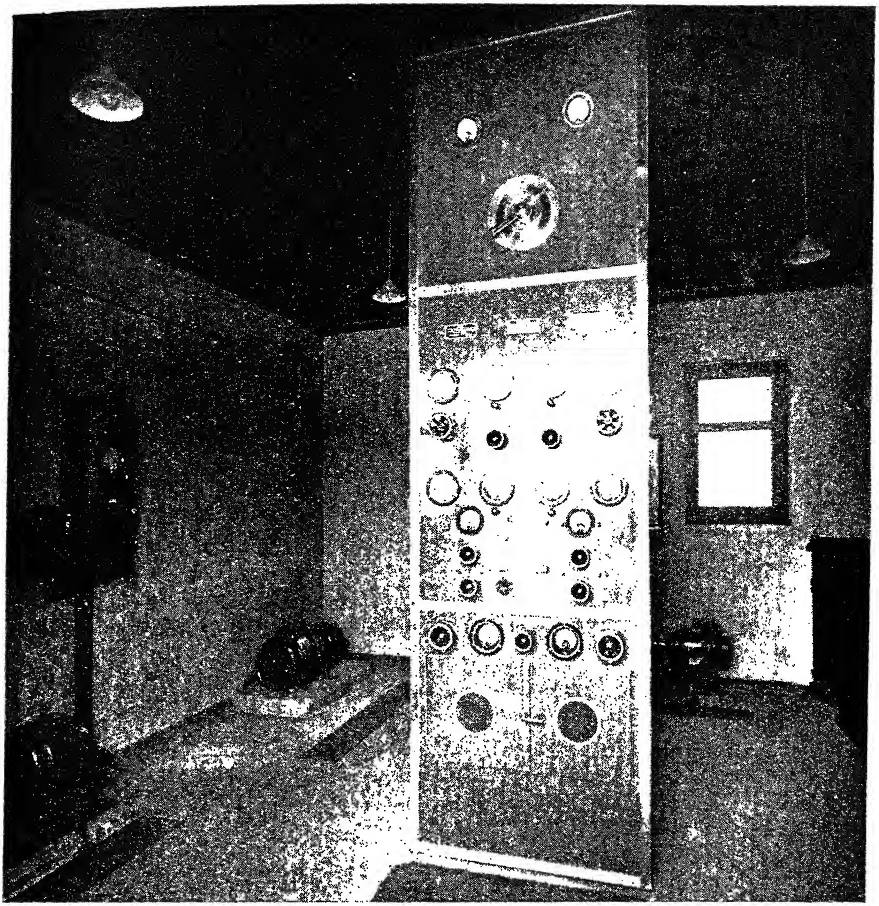


Fig. 5.—MARCONI VISUAL BEACON TRANSMITTER AT CROYDON AERODROME.

(*b*) (ii.) This system is similar to (*b*) (i.) except that the antennæ are energised with a constant carrier modulated by some suitably chosen low frequencies differing from one another by about 20 cycles, a single modulating frequency being applied to each branch of the aerial system. The four equi-signal zones are obtained by slightly misphasing the currents applied to adjacent branches of the antenna system.

Here again, this is a type of beacon at one time used for navigational purposes, but, although a sound system, is not now employed because visual indication can be obtained in the aircraft by using other transmitting systems of a less complicated nature.

(*b*) (iii.) This type of beacon first originated in Holland and comprises an aerial system having a single closed loop and a "vertical" aerial. The loop is energised by a continuous carrier wave, the "vertical" aerial emitting a pre-arranged combination of dots and dashes alternately. The currents in the "vertical" aerial are so phased that at one instant they are in phase with the current in one half of the loop, and at the next with the current in the other half. Thus, a heart-shaped polar diagram is produced, the maximum radiation from which alternates in direction by 180°; dots predominating in one direction, dashes in the other. An equi-signal zone will be produced on either side of a line drawn at right-angles through the centre of the loop aerial. In this zone a continuous signal will be received, dots or dashes being heard as one proceeds to one side or the other of it.

A station of this type, together with associated marker beacons, has recently been installed by the Marconi Company at the Liverpool Airport.

The ultra high frequency beacon system described further on in these notes presents no advantages over those possessed by the so-called "Dutch" beacon. Provided that marker beacons are installed and the aircraft is equipped with a sensitive altimeter, it is possible for pilots to fly along the horizontal beam from the main beacon until they reach the outer marker. Knowing the distance between the outer and the inner marker beacons, it is comparatively easy to adjust the glide of the aircraft so that, when the signal from the inner (or boundary) marker is heard, it is at a height from which the landing can be made in a normal manner. An added advantage, of course, is that no additional receiving apparatus is required, although an attachment, giving visual indication of the main beacon signal, can be added if required. This attachment consists of a rectifying system, the output from which actuates a milliammeter of the centre reading type.

(*c*) This type of beacon was developed by the Royal Aeronautical Establishment, but the commercial rights are held by the Marconi Company. It consists of a single frame aerial which rotates clockwise once every minute. A "starting" signal, consisting of a characteristic Morse symbol, is transmitted when the frame passes through 0° and again at 90°. Two "starting" signals are necessary, since an observer situated on the North-South line would not hear the Northern "starting" signal since he would be in the region of least signal intensity. By

observing the time taken between the "starting" signal and the disappearance of the signal, one's bearing in relation to the beacon station can be obtained. To facilitate operations, special stop-watches calibrated in degrees can now be obtained, thus enabling direct readings to be taken.

This type of beacon has not received very much attention and is only of use for navigational purposes.

(*d*) The ultra high frequency beacon was first developed in America. The most frequently employed system at present is that developed jointly by Telefunken and Lorenz in Germany for the Air Ministry of the Reich.

This type of station consists of a transmitter which feeds a dipole aerial, on either side of which is a reflector which can be open-circuited. If these reflectors are keyed alternately, one by dots and the other by dashes, two equi-signal zones will be created—one in front and one behind the beacon station. The action of keying the reflectors results in the production of a field pattern in which the maximum radiation is at right angles to the centre of the equi-signal zones. It will be seen therefore that, despite the fact that the radiation on 9 metres attenuates very rapidly at ground level, there is a great danger of interference occurring in aircraft flying at a height on a beacon of similar type some distance away, the amount of interference depending upon the distance between the two beacons and the height at which the aircraft is flying. Of course, this state of affairs can only occur if the two stations referred to above employ the same frequency, but it is a point which requires serious consideration in a country where several beacons are to be installed.

If two marker beacons are provided—one situated at a distance of a mile or so from the boundary of the airport and the other on the airport boundary itself—a pilot can, by adjusting his angle of glide as soon as he hears the signal from the outer marker, arrange to be at such an altitude over the boundary marker as to permit him to make a safe landing by ordinary blind flying methods. It is assumed, of course, that aircraft wishing to alight in conditions of bad visibility would be carrying sensitive altimeters.

Owing to the amount of energy radiated by this type of beacon in unwanted directions, it is necessary to employ a relatively large supply of power.

(*e*) This system which has been developed by the Marconi Company works on the same wavelengths as that employed by the Telefunken and Lorenz systems, but it possesses two unique features :

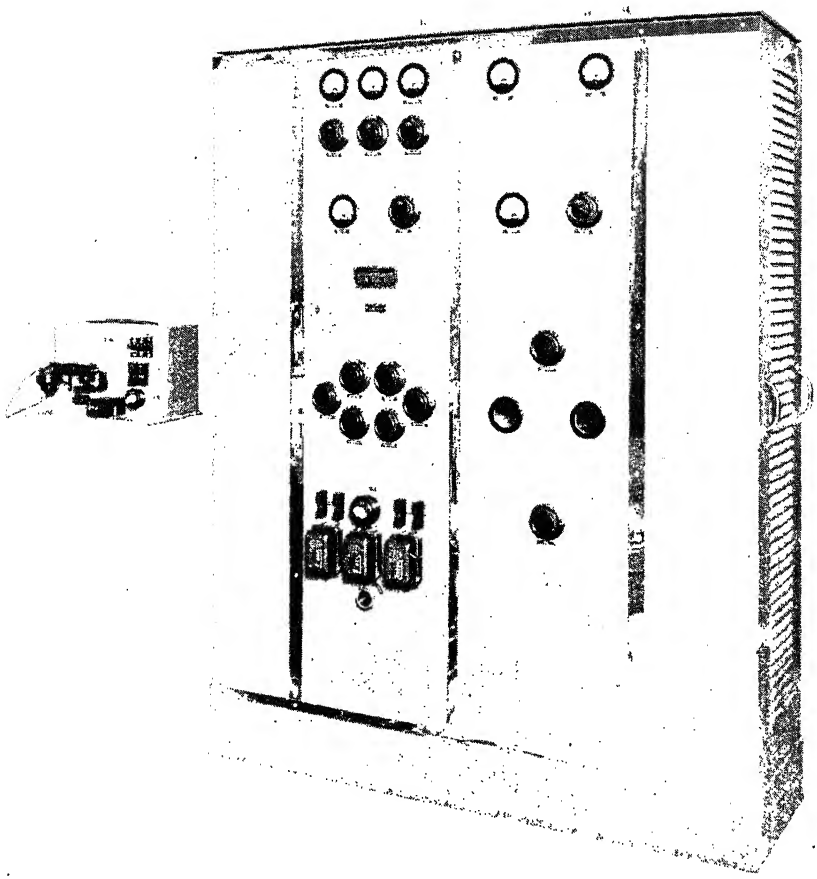


Fig. 6.—MARCONI AURAL BEACON TYPE WBD49, MODEL NO. 1089, FOR LIVERPOOL.
Spot wave 355 kcs., C.W. signal. Letters for transmission ET on frame aerial 100 watts, on open aerial 20 watts. Local or remotely controlled. Employs two marker beacons.

(i.) The radiation is sensibly concentrated in the desired direction, *i.e.*, on the borders of the equi-signal zone. This enables a considerable saving to be made in the power required to operate the station, resulting in lower prime and maintenance costs.

(ii.) Only one equi-signal zone is normally provided, which results in all ambiguity being avoided and, in certain circumstances, eases the problem of the control of aircraft in the vicinity of busy airports.

Because of the way in which the radiation is concentrated, it is possible to reproduce the ranges obtainable from the

Telefunken and Lorenz radio beacons by the employment of approximately one-third the power.

(*f*) Marker beacons are employed with approach beacons to indicate to a pilot his distance from the landing area. In America, they are also used to indicate the intersection of equi-signal zones projected from different airports. They can be divided into the following categories :—

(i.) Medium wave route marker beacons.

(ii.) Medium wave outer and inner marker beacons for use with medium wave approach systems.

(iii.) Ultra high frequency outer and inner marker beacons for use with ultra high frequency approach systems.

(*f*) (i.) These stations comprise low powered transmitters which radiate energy from vertical antennæ and transmit a characteristic Morse identification signal.

(*f*) (ii.) These types of beacon are arranged to transmit on the same frequency as the main beacon with which they are associated, but the emission is " wobbled " so as to cover a band 4 kcs. wide, *i.e.*, the frequency of the main beacon—2 kcs.

(*f*) (iii.) Marker beacons associated with ultra high frequency approach beacons transmit on 7·9 metres. The signal transmitted from the outer marker consists of a dash 2/5ths of a second in duration, followed by a space 1/10th of a second in duration, whilst that from the inner marker consists of a dot 1/10th of a second in duration followed by a space 1/15th of a second in duration.

In countries where there is no congestion in the bands allotted to the aeronautical services, the medium wave system described in paragraph (*b*) (iii.) is probably more suitable, since it permits the normally carried medium wave receiver to be used for approach work, thus avoiding the necessity for extra receiving equipment of a complicated nature and which will only work satisfactorily when both the bonding and ignition screening systems of the aircraft are perfect. Actually, it is difficult to see what technical advantages are possessed by the ultra high frequency system in countries where there is no great congestion in the medium wave band.

FREQUENCY BANDS ALLOTTED TO THE AIRCRAFT SERVICE AT PRESENT

At present the majority of communication in Europe between aircraft and ground station takes place on medium waves and frequencies within the band 320–365 kcs. (938–822 metres) are utilised as follows :—

363 kcs. (826 metres). R/T. and W/T. waves.
355 kcs. (845 metres). Radio beacon waves.
348 kcs. (862 metres). R/T. and W/T. waves.

342 kcs. (877 metres) 340 kcs. (882 metres) 338 kcs. (888 metres) 336 kcs. (893 metres)	Ground station working frequencies.
333 kcs. (900 metres).	General calling and distress waves.
327 kcs. (917 metres).	Transmitting wave for aircraft requiring bearing.
322 kcs. (932 metres).	Controlled zone wave.

In order to reduce to the minimum the length of the messages transmitted between airport radio stations and aircraft, four codes have been introduced :—

(*a*) The Q code, consisting of three-letter groups commencing with the letter Q, which enable the following information to be exchanged:
- (1) Reciprocal recognition between stations.
- (2) Information concerning the radio service.
- (3) Radio operation, *e.g.*, establishment of communication, routing of messages, etc.
- (4) Operation of aircraft, *e.g.*, movements of aircraft, general air navigation, D.F. positions and bearings, approaches to aerodromes, radio beacon landing signals, control zones, lighting of aerodromes, meteorology and meteorological advice, messages relating to accidents and danger.

(*b*) Miscellaneous abbreviations used in connection with the handling of correspondence.

(*c*) Service signals.

(*d*) The ZZ code which is used in connection with bad weather approaches to airports.

Details of the first three codes can be found in " Air Publication 1529 " (abbreviations to be used in the Civil Aeronautical Radio Service), obtainable from H.M. Stationery Office, and details of the ZZ code will be found in various Notices to Airmen.

In addition to the above, a phonetic alphabet has been drawn up for use in radio-telephonic communication, details of which will also be found in " Air Publication 1529."

THE BRITISH AUTOMATIC PILOT

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

THE British Automatic Pilot, known to the Royal Air Force as the Automatic Control, is the invention of Messrs. P. A. Cooke and F. Meredith, scientists in the employ of the Air Ministry. The Royal Aeronautical Society considered the invention to be of sufficient merit to warrant the award of the Silver Medal, in April 1937. The patents, as far as commercial use is concerned, are the property of Smith's Aircraft Instruments. Large numbers of these automatic controls are in use by the Royal Air Force all over the world, particularly in bomber aeroplanes, and are also being fitted to civil aeroplanes.

Purpose of the Automatic Control

It was originally fitted to night bombers, which might have to fly for as much as ten hours at a time in the dark, in bad weather, and through or over cloud, extreme accuracy of navigation being an absolute essential. Use such as this gives the key to its purpose and advantages : it relieves the human pilot of strain both mental and physical, so that he is fresh when a night landing is required ; it frees him from the controls and permits him to calculate or signal ; it economises fuel and makes flying more comfortable because it corrects any pitching or deviation before a human pilot would become aware of it ; and the sum of these advantages makes it possible to dispense in emergency with a second pilot or a wireless operator, with a consequent increase in bomb-load or pay-load, as the case may be.

This type of automatic control was used in the British long-distance flight towards Capetown, over 5,000 miles in a single flight. A similar instrument is used in the Queen Bee aeroplane targets, which provide naval gunners with a full-sized aeroplane instantly responsive to signals ; at which, since it is pilotless, guns can be aimed directly and hits accurately registered, without the necessity for aiming off.

Functioning of the Automatic Control

The first pilotless controls made in this country were of the two-axis type, working only on rudder and elevator ; disturbances which would normally be corrected by means of the ailerons were left to the dihedral. The present-day British Automatic Pilot has one gyro for rudder and elevator and a second for ailerons, control being exercised in all three axes.

Consider the actions involved in a single axis such as the yawing axis —controlled by the rudder—when a human pilot is in charge :

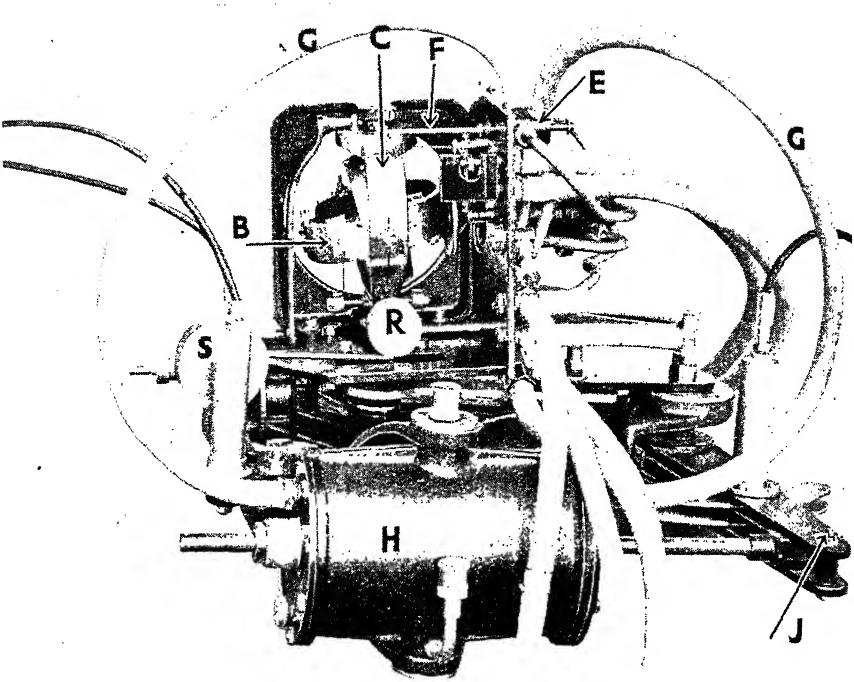


Fig. 1.—THE CONTROLS OF THE BRITISH AUTOMATIC PILOT.

B and C, gimbal rings; E, valve; F, link; GG, pipes; H, servo motor; J, dummy rudder; R and S, weights.

(i.) Eyes and brain tell him when the aeroplane deviates from the set course.
(ii.) Nerves carry the message from his brain to leg muscles.
(iii.) One leg and foot move the rudder bar in the appropriate direction, and the aeroplane begins to turn back on to its course.
(iv.) When it is again on its course, brain, nerves and muscle combine to restore the rudder bar to a neutral position.

Control by an automatic pilot is no more complex, and follows the same sequence:

(i.) The gyroscope, running at 11,000 revolutions per minute, tends to remain fixed in space; if the aeroplane deviates from the fore and aft line which is coincident with the correct course, the gyro spindle remains pointing along that line, and the aeroplane turns about the gyro.
(ii.) The slightest turn of the aeroplane relative to the gyro is transmitted from the gimbal by means of a slender rod to a piston in a small valve with two ports. These might be styled the

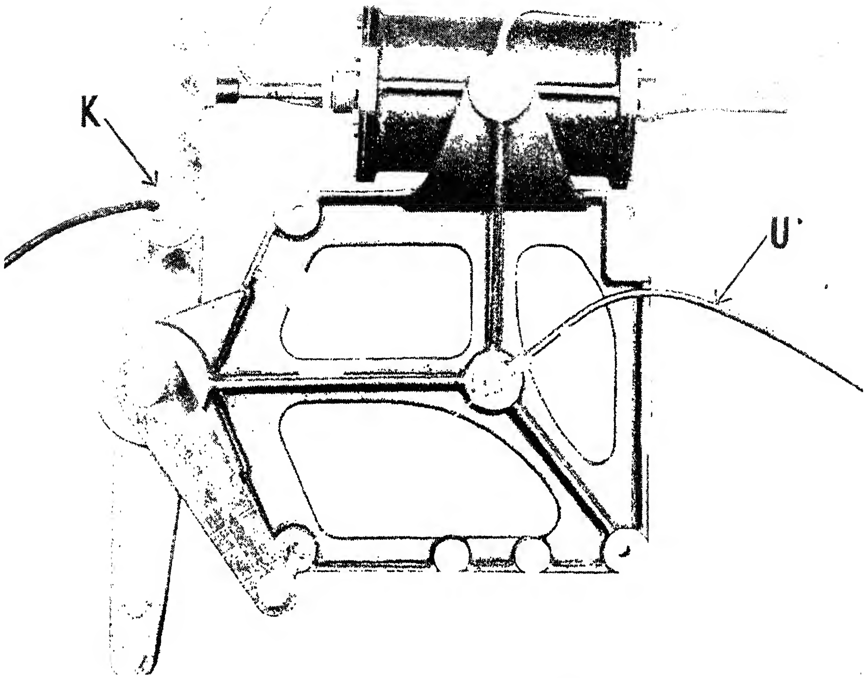


Fig. 2.—ELEVATOR SERVO-MOTOR AND MOUNTING.

PUSH and PULL ports respectively. One of them is uncovered by the movement of the piston, following that of the gimbal ring.

(iii.) Compressed air is thus enabled to flow to either the PUSH or the PULL side of a large piston connected to the rudder bar. The piston and cylinder together form the servo-motor.

(iv.) Rotation of the rudder bar rotates also, very slightly, the framework of the gyro and its gimbals, constituting a "follow up system" which will result in the rudder bar returning to neutral as the aeroplane comes back on course.

The Compressor System of the British Automatic Pilot

It will now be possible to proceed to a consideration of the details of the British Automatic Pilot, which, unlike other types, operates on compressed air alone, both for driving the gyro and operating the servo-motors. "Not only does this tend to greater simplicity, as only one compressor is required and all pneumatic-hydraulic relays are rendered unnecessary, but the direct operation of the servo-motors results in a large reduction of lag. A reduction of servo-motor lag is of vital importance, since far better damping of the aeroplane oscillations is thereby achieved." *

* "The Automatic Pilot Instruction Manual," p. 4. (Smith's Aircraft Instruments, 5s.)

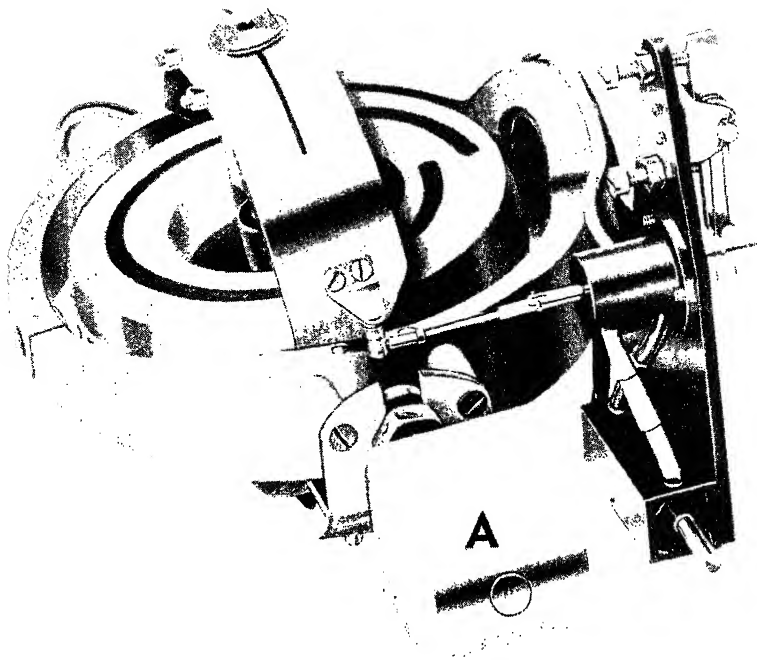


Fig. 3.—GYROSCOPE OF AILERON CONTROL.

The air is supplied by a self-contained compressor, at a pressure of 35 lb. to the square inch. On practically all Service aeroplanes at present the compressor is driven by a windmill; but in course of time this will be superseded by compressors coupled to the main engines, in the same way as other accessories such as the electric generator, fuel pump and, of course, the magnetos.

Description of Rudder and Elevator Control

The detail of the complete set of controls for two of the axes is best seen from Fig. 1. The gyro wheel is seen in its gimbal rings B and C; not clearly visible in the illustration, there is a series of pockets or buckets cut in its rim, and the compressed air impinges on these from jets fed through the hollow bottom pivot of the outer gimbal ring.

The link F connects the gimbal ring with the valve E, which admits the compressed air through either of the pipes GG to one side or the other of the piston of the servo-motor H. The piston rod is connected to a dummy rudder J.

The rudder and elevator control is seen as it would appear in an aeroplane viewed from one side, and the dummy rudder bar is parallel

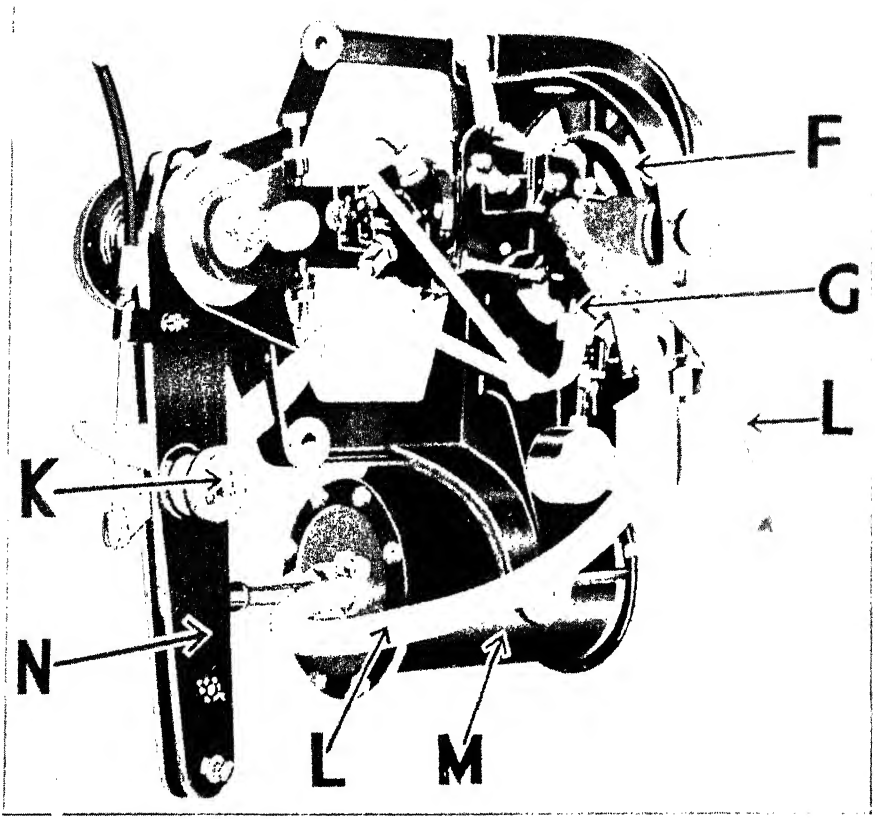


Fig. 4.—THE COMPLETE AILERON CONTROL.

to the main rudder bar. The illustration will show that the spindle of the gyro wheel is in the fore and aft line of the aeroplane. While a rudder control could be operated just as well if the spindle were at right angles to the position illustrated—that is, across the aeroplane—the same gyro could not then be used for elevator control.

As soon as there is an alteration in the pitch of the aeroplane, the frame L of the gyro begins to rotate about the gyro wheel; and this slight movement is transmitted to an elevator valve and thence to the elevator servo-motor, just as in the rudder control.

It is, however, necessary to maintain the relationship of the pitch datum

provided by the gyro with that of gravity; this is provided by a linked system of weights R and S; one weight would be sufficient, were it not for the action of centrifugal force exerted upon it when the aeroplane makes a flat turn.

In Fig. 1 there are two horizontal pipes to the right of weight R. These connect the elevator valve to its servo-motor, shown in Fig. 2. The Bowden cable U is the follow-up connection to the *body* of the elevator valve.

The Aileron Control

The use of automatic controls in flight and maintenance on the ground are dealt with elsewhere in this work, but it may here be mentioned that as practically all flight under automatic control is in a straight line, the aileron control of this type is designed only for flat turns, that is those made of so large a radius as to require practically no bank. The gyro spindle is horizontal and athwartships of the aeroplane; the function of gyro, valve and servo-motor is exactly as previously described. As in the elevator control, a small weight is fixed, like a pendulum, to the bottom of the outer gimbal ring to ensure, in conjunction with the rest of the mechanism, that the gyro spindle remains horizontal. This is clearly shown, marked A, in Fig. 3, the gyroscope of the aileron control. This view is taken at an unusual angle, from almost underneath the gyroscope, in order to show this erecting mechanism.

The complete aileron control is shown in Fig. 4. The gimbal ring is at F, connected by a link through a relay valve to the aileron valve G; pipes LL connect the valve to servo-motor M, the piston of which operates on the control column through a dummy control bar at N.

THE REID REACTION TESTER

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

THE Reid Pilot Testing Apparatus was devised to eliminate at an early stage candidates who are likely to prove bad pilots. Its use reduces the incidence of crashes and loss of life; and it also pre-selects pupils who are fitted by temperament to become fighter pilots, as compared with those with less rapid reactions. Designed and developed by Squadron Leader G. H. Reid, D.F.C., whose Turn Indicator is fitted to every Royal Air Force aeroplane, the apparatus has shown itself to be amazingly efficient in determining the flying aptitude of candidates for training.

Quickness of Response to an External Stimulus

The general purpose of the apparatus is to test the quickness of response to an external stimulus, and in this case the stimulus has been associated with the actions involved in flying. In the air an aeroplane may be thrown into attitudes other than that of straight and level flight. If the aeroplane were allowed to remain in such attitudes without an immediate correctional movement, it might get out of control; and in general, other qualities being equal, the most efficient pilot is the one possessing the most rapid response and the quickest movements which will restore the aeroplane to its normal position in straight flight.

The Reid Reaction Tester has been specially designed, therefore, to test the speed of reaction of would-be pilots in making the restoring movements of control column and rudder bar, and bringing each of these, or both control column and rudder bar at once, back to the neutral position of each with the least possible waste of time.

Recovery from Attitude of Spinning

The reactions of a pupil pilot can by this means be tested in regard to movements of his hands alone, either the movements required by variation in pitch of the aeroplane, or variation in bank, or both together; and similar tests can be made upon rudder bar movements alone, or in combination with the two other movements of the control column. All three in combination are necessary when an aeroplane is to be recovered from the attitude of spinning; and the most severe test of the Reaction Tester involves frequent measurement of the reaction time required for recovery from an attitude of spin.

Several such tests can be made and this is a necessity for the most

efficient use of the apparatus. On a single trial, the would-be pilot might by a fluke show a brief reaction time, but he could not be judged upon this alone, and his recovery should be tested at least ten times.

Such a repetition of tests provides information in regard to another quality which the pupil must possess if he is to become a successful pilot—the quality of steadiness. It has been said above that by a fluke a single test might show a brief reaction time; and if some of the tests were very brief and some others very long, showing an erratic curve of reaction times, it might be taken that such a pupil is in all probability deficient in the amount of steadiness which would show approximately the same reaction time for each of ten recordings.

Description of the Apparatus

The Reid Reaction Tester is in general appearance like the centre portion of the cockpit of an aeroplane. Inside that cockpit are found the usual pilot's seat, a control column, and a rudder bar; but in place of the instrument board a series of coloured lamps is so arranged that any displacement of either the control stick or rudder bar from the centralised position is at once apparent by the illumination of red or green lamps—red for port and green for starboard. These lamps correspond with aileron, elevator and rudder control and when all controls are central white lights only appear.

The "subject" is given an explanation and trial demonstration, and is then left to centralise the controls from extreme position, the time taken being recorded by a special charting device. Records are taken for the movements of either hand or foot separately or in any combination. Ten records of each separate movement and twenty of the combined movement are charted and averaged. The effect of the introduction of extraneous noises such as that of a Klaxon horn can be investigated.

Movement of Control Column

In this apparatus it is not necessary to tilt the whole of the fuselage and a much simpler method of recording reaction times has been devised Behind the dashboard of the cockpit is mounted a curved mercury tube to which are connected a number of electrical contactors. Considering for a moment the movement of the control column alone, a movement to the extreme position equivalent to full bank either to left or right, wil tilt the mercury tube; and the mercury movement over the contacts closes a number of electrical circuits and lights up a semi-circular bank o lamps in turn. The degree of turn is shown by the number of lamps lighted and the direction of tilt by their colour, red for port, green fo starboard. The centre lamp of this arc is a white one.

A second series of lamps appears on the dashboard to one side of those representing movements of the control column to right or left, and thi second series indicates fore and aft movements of the column. It is

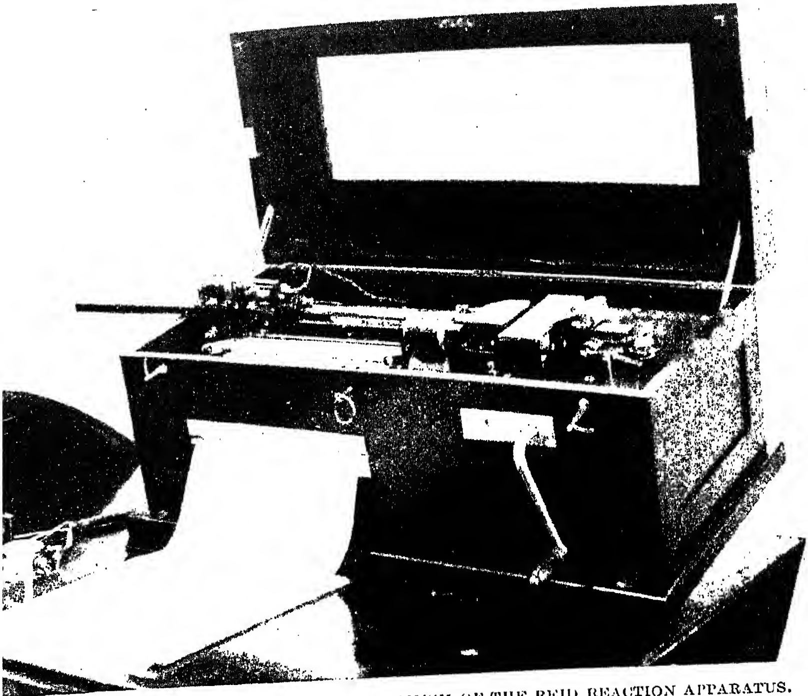


Fig. 1.—THE RECORDING MECHANISM OF THE REID REACTION APPARATUS.

straight vertical line of lamps, the central one being white as before, those above and below the attitude of normal level flight being red and green respectively.

Below the arc of lamps, a straight horizontal row, once again with the central lamp white, shows turns to port or starboard and the extent of such turns.

If the control column and rudder bar are perfectly central, white lights will be shown on each of the above-mentioned indicators.

The Recorder

One of the greatest advantages of the apparatus is that it has been fitted with a specially designed recorder, illustrated in Fig. 1, which writes or charts a line proportional in length to the time taken for any particular movement, for two movements together, or for all three in combination. It consists of a spring-driven drum bearing a roll of the special paper used for these tests ; a pen travels across the paper according to movements of rudder bar and control column ; but is not operated unless the instructor closes a switch coupling up the pen actuating gear and the cockpit controls.

The recording mechanism can be entirely disconnected from the cockpit by means of a jack plug, and this ensures that no damage will be done to the recorder by pupils who may wish merely to practise the movements of the controls without a written record being made.

Extent of Mental Disturbance

One other quality can be tested by this apparatus; and that is the extent of mental disturbance and its effect upon reaction times should any violent external stimulus be applied to the mind of the pupil. That stimulus is supplied in this apparatus by means of a loud Klaxon horn fitted in a concealed position in the cockpit. At a certain moment in the series of more complex tests (with long reaction times) the Klaxon is pressed for a moment or two and the recording tests remorselessly continued.

The mental disturbance resulting from this causes immediately a marked increase in the reaction time of the movement being carried out; pupils who will make good pilots are not greatly influenced, however, in the reaction times of movements following that particular one; but in those of a somewhat lower quality, the disturbance is prolonged over the next half a dozen movements of the controls, and the reaction times in some of them may very well exceed the one in which the disturbance actually took place.

How the Reaction Tester is Used

The apparatus is best used :—

(*a*) At the beginning of training to assess potential aptitude.

(*b*) At any time during training to assess, in conjunction with Instructors' Reports, lack of progress.

(*c*) To elucidate the cause of bad performance.

It may be used also as deemed necessary as a practice apparatus for speeding up slow performance.

Practice on the apparatus enables pupils, some more than others, to absorb instruction more easily, since they acquire thereby the instinctive movements used in flying. It can, therefore, be used profitably by pupils on non-flying days as a form of practice.

It should, however, be noted that daily practice may endow a pupil with an undue amount of skill in working the apparatus which is out of proportion to his actual skill in the air, with the result that he will write a curve which is not a correct indication of his real flying ability. The amount of practice on the apparatus, therefore, should be taken into consideration when assessing aptitude from " end of term " curves.

Routine Tests

For assessing aptitude a standard routine is employed: testing hands alone, first of all with the control column hard over to the left,

and then centralising it, followed by a similar series of centralisation from hard over to the right; then a series of feet movements from full left rudder to the centre, followed by a series from full right rudder to the centre; and lastly hands and feet combined, full stick and full rudder. A series of practice movements is carried out with the lights working but with the recorder not connected, until such time as the pupil has thoroughly grasped the method of using the apparatus and has overcome his nervousness of the controls.

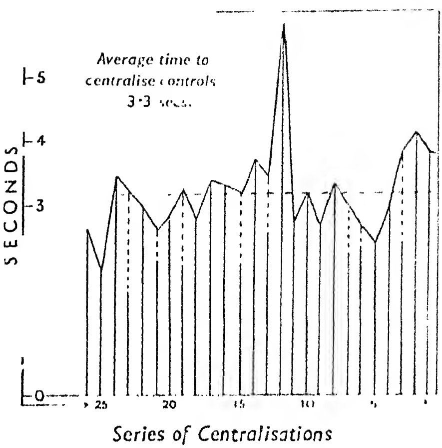


Fig. 2.—CHART OF REACTION TIMES DURING SPIN MANŒUVRE.

The tests can be used to emphasise that the control column should be held firmly but lightly; an effort to centralise the controls more rapidly than they could possibly be centralised in an aeroplane, automatically defeats itself by swinging over beyond the central light; the rate of movement (for other than erratic pupils) is sufficient to extinguish the lights in sequence until only the white central light remains on, without any overswing. Overswinging is more common with the rudder than with the control column and slightly longer practice is required.

Controls in Combination

Perhaps the most important test is that for the controls in combination; and it is usually explained to the pupil that arms and legs should function together at the beginning, but that the rudder movement should be completed just before the control column reaches the central position. During the practice stage, the pupil is warned that the Klaxon may be sounded at any moment, but it is not so sounded until the recorder is in action, and the pupil has been warned also that he is to take no notice of it if possible, and to continue performing subsequent movements.

Assessment of Charts

The result of the above tests is a series of lines on the chart paper, and it is usual to join the tops of all these vertical lines, providing a curve of varying regularity according to the skill of the pupil. The chart will then look like Fig. 2. The height of each line is measured, an average struck, and a horizontal line drawn to indicate this average. The height of this line above the zero gives the average time for the test, the scale of the chart being 0·8 of an inch for one second.

The effect of steadiness on the curve has been previously mentioned; and the most important points to notice are the regularity and the average time. No attention is paid to the reaction time measure while the Klaxon is being sounded, but only to its after effects. In unstable pupils, the chart may be very much worse ; in really high quality subjects, even an improvement in performance may result, showing exceptional self-control.

Medical Opinion

Research work by the R.A.F. Medical Laboratory has determined the times which it takes for an average pupil to react to these tests. These are as follows :—

Feet.	Hands.	Combined Movement.
1–1·5 secs.	1·8–2·2 secs.	3–4 secs.

Shorter times than these would indicate that the pupil being tested will probably become a pilot above the average, with sufficiently quick reactions to qualify as a fighter pilot ; while slower times indicate not only that as a pilot the prospective pupil would be below the average, but might not be worth the time and expense of training.

The following phrases are extracted from a report by Royal Air Force Medical Officers :—

" The instrument predicts with extraordinary accuracy in the majority of cases as to probable ability as a pilot. Further, it would appear to be very questionable whether it is worth while accepting a candidate who cannot do better than about 4·5 or perhaps 5·0. The few who obtain that figure and who may turn out more or less successfully are probably not worth the expense and time spent on them.

" This apparatus can be of definite value :—

" (*a*) By assisting in the earlier elimination of unsound pilots and thereby effecting economies by further reducing wastage both in training and Service units.

" (*b*) By assisting in original selection and thereby effecting considerable economies by reducing wastage in *ab initio* training.

" (*c*) By assisting in the actual flying training of pupils."

The apparatus can also be used to test the speed of reaction of motor transport drivers ; and it is found possible to pick out drivers whose reaction times are so slow that they may be regarded as " accident prone."

REID PICKETS AND GRAB HOOK

By Wing-Commander G. W. Williamson, O.B.E., M.C., M.Inst.C.E., M.I.Mech.E., M.I.E.E.

REID AIRCRAFT PICKET (CARVER TYPE)

In the early days of flying when aerodromes and hangars were scarce, it was frequently necessary for aeroplanes to be picketed out in the open pending a resumption of the journey next day. The Royal Flying Corps in those days was accustomed to a particular type of picket, a variation of the screw picket, which at that time was used for the bracing of Bessonaux hangars or portable tent hangars which were almost the only accommodation for aeroplanes away from their own stations.

That picket, like a corkscrew, was exceedingly heavy, being made of wrought iron and over 3 ft. long. An aeroplane was picketed out by being anchored down to one of these huge pickets at the end of each wing tip; larger aeroplanes might have two to each wing, as well as one or two to which the tail skid could be fastened. The total weight of the set was 40 or 50 lbs., and the bulk very considerable.

The Carver Aircraft Picket

The Carver Aircraft Picket was specially designed to replace this heavy and cumbersome type of screw picket. One screw picket is replaced by a pair of straight pickets and a cross-piece as shown in the centre illustration of Fig. 1. The separate pickets are illustrated at the sides, showing their simplicity and light weight; and across the foot of the illustration is shown one pair of pickets complete with the cross-piece strapped together for convenience in transport.

Pickets are made of stout molybdenum steel tubing, with forged T-shaped heads and solid points. The whole set is cadmium plated and is, therefore, rust proof.

Method of Use

When fully assembled, the set would appear as in the centre illustration of Fig. 1, except that each picket is driven into the ground almost up to its head. It will be seen that both pickets pass through the cross-piece; and it is vitally essential that the flat stays of the cross-piece are vertical so as to stand up to a vertical pull.

When it is required to use the Carver Pickets, one picket is inserted into the tubular part of the cross-piece (care being taken that the flat stay is vertical) and the picket is driven into the ground at an angle of

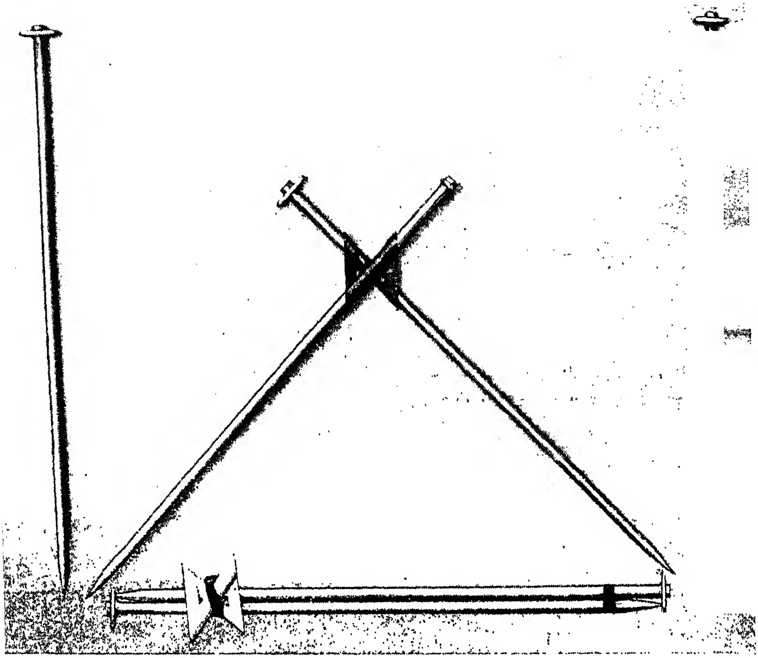


Fig. 1.—THE REID & SIGRIST AIRCRAFT PICKET (CARVER TYPE)

45 degrees ; the other picket is passed through the remaining tubular portion of the cross-piece and driven in at right angles to the first one. The aeroplane can be anchored down to the cross-piece ; the set is far more efficient than the screw picket.

Dimensions and Weight

These pickets are made in two sizes :

Size.	Length of picket.	Weight of set.	Test load.
Heavy . .	3 ft.	5 lbs.	14 cwt.
Light . .	18 in.	$2\frac{3}{4}$ lbs.	8 cwt.

The larger size is in use by the Air Ministry and by the air forces of Continental Powers. The smaller type is made for light aeroplanes.

Reports of Trials

When these pickets were first supplied for Air Ministry use, they were put through drastic tests which proved that they were in every way superior to the corkscrew pattern, quite apart from the considerable reduction in weight and very much greater portability.

The heavy pattern withstood more than a ton of direct lift in hard

ground; and even then there was no damage whatever to the pickets, but several cubic feet of the ground began to lift in one solid mass.

When tested in the sand of semi-tropical countries such as Egypt or Iraq, this type of picket gave equally satisfactory results and has been for some years in service.

Maintenance and Portability

As stated previously, every part is cadmium plated and unless the picket is in constant use there will be no trouble whatever with rust. If however, pickets are frequently used in stony ground or in an abrasive soil such as the Egyptian sand, the cadmium plating of the extreme point may in time wear off; replating is a simple and inexpensive job, but if it is not convenient to return the pickets, an occasional rub with an oily rag will maintain the points in good condition. It is not recommended that the points should be thickly greased or heavily oiled when the pickets are being carried in aeroplanes and this simple operation might well form part of the routine inspection of the aeroplane once a week.

The illustration does not show that the forged head is made with two small eyes. When the pickets are to be collected for carriage, the point of each is inserted in this small hole, ensuring that the sharpened end is sheathed and cannot possibly tear the fabric of the aeroplane or the clothes of the occupants. The two pickets are then strapped together, the cross-piece being looped on to one of the straps as shown in the bottom illustration of Fig. 1.

THE REID AND SIGRIST GRAB HOOK

A grab hook, for use in fire-fighting, forms part of the equipment of every aerodrome. Its general appearance and method of use are shown in Fig. 2; and its greatest advantage is that in an aeroplane fire the blazing *débris* may be scattered, clearing the way to the imprisoned occupants. It is therefore carried on the fire tender. Quite apart from aerodrome work, it is used by municipalities as part of the equipment of their fire engines; by factories for salvage work; and frequently forms part of the equipment of garage breakdown cars.

Construction of Grab Hook

The grab hook itself consists of a case-hardened carbon steel forging, which is fixed to a 12-ft. steel tube hinged in the middle by means of a patented folding device. When folded the appearance of the grab hook is shown in Fig. 3.

From the hook, through the tube, runs a cable approximately 24 ft. long, 12 ft. of which is, therefore, exterior to the steel tube. To that exterior portion are attached three strong wooden handles, which provide

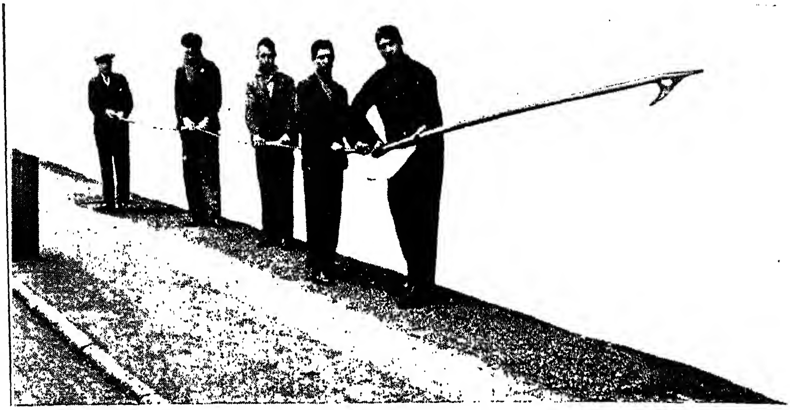


Fig. 2.—REID & SIGRIST GRAB HOOK.

a powerful purchase by means of which it is possible to tear away portions of a blazing aeroplane.

From Fig. 3 it will be seen that when not in use the end of the cable, together with its wooden cross-pieces, can be packed in a bag made of stout Willesden canvas, loosely pushed on to the steel tube. It is a matter of seconds to release the cable from the bag, extend the tube, which is locked by a bayonet joint and to remove the stout leather cover which protects the point of the hook—not shown in these illustrations.

The whole apparatus is protected against corrosion by heavy cadmium plating.

At the left-hand end of Fig. 3 the curve of the cable can be seen as it passes from one half of the tube to the other ; and just above it is the locking device which fixes the bayonet joint. Grab hooks supplied to the Air Ministry are frequently made with a screwed joint instead of the type illustrated.

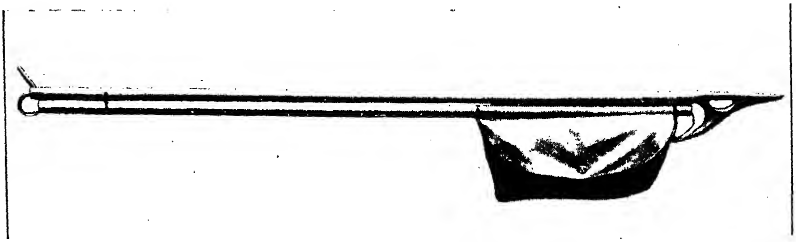


Fig. 3.—GRAB HOOK FOLDED.

AERO ENGINE DESIGN

By Squadron-Leader H. Nelson, M.B.E., M.I.B.E., A.M.I.Mar.E.

The Internal Combustion Engine

THE term "internal combustion" is applied to engines in which the heat of combustion occurs inside the engine cylinder. In the "external combustion," or steam engine, the heat of combustion from the fuel occurs outside the engine cylinder, as in the boilers. In both types of engine the heat generated from fuel is the source of power. In the internal combustion engine the heat energy is derived by igniting a fuel vapour and air mixture compressed by a piston inside the cylinder, the piston being forced downwards by the high pressure generated from combustion; the heat energy is thus converted into kinetic energy. The piston is attached to a crank-shaft by a connecting rod. This converts the linear motion of the piston into rotary motion of the crankshaft which, in the case of aeroplane engines, turns the airscrew.

Cycle of Operations

In order to obtain continuous rotary motion, an engine must perform the following operations continuously. The cycle of operations must consist of:—

(*a*) The admission of a correctly proportioned mixture of fuel vapour and air into the cylinders.
(*b*) The compression of the mixture.
(*c*) The burning of the compressed mixture.
(*d*) The expulsion of the burnt gases.

There are two methods of performing these operations. These are known as the two-stroke cycle and the four-stroke cycle. The latter is known as the Otto cycle and is in general use for aeronautical purposes.

Two-stroke Cycle

In the stroke from the top to the bottom of the cylinder in this cycle of operations the expansion of the burnt gases forces the piston downwards, and in so doing opens the exhaust port and therefore allows some of the gases to escape under their own pressure. As the piston moves farther downwards it uncovers the inlet port and allows the fresh charge of mixture to enter the cylinder. The downward-moving piston causes a pressure to be set up in the crankcase, this pressure forces the new charge from the crankcase through a transfer port to the inlet port and thence to the combustion chamber. A deflector on the crown of the piston causes the new charge to be deflected upwards, thus forcing the remaining burnt gases downwards and out of the exhaust port. The

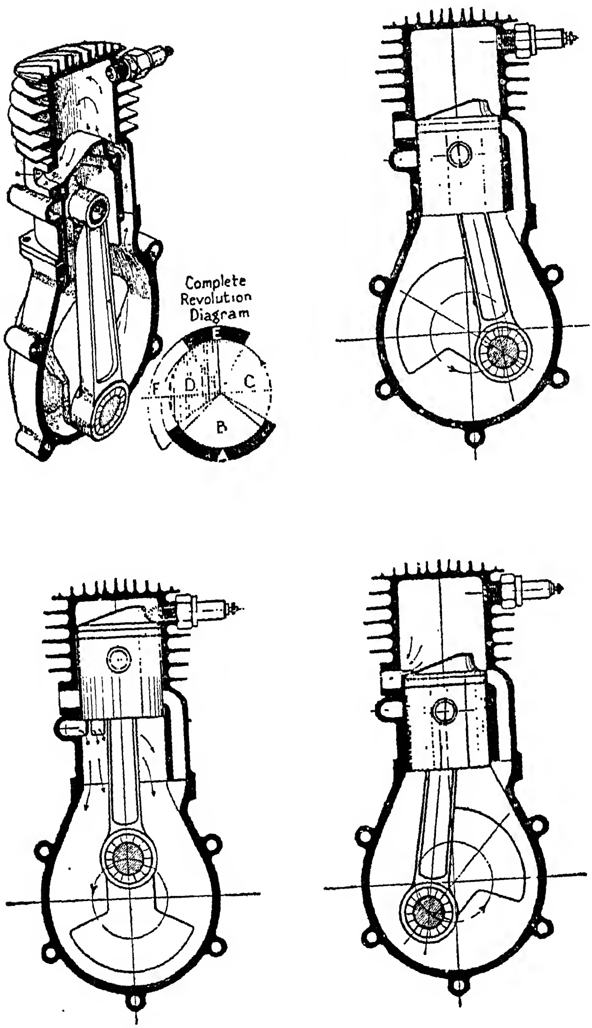


Fig. 1.—TWO-STROKE CYCLE OF OPERATIONS.

piston then ascends, closing the inlet and exhaust ports in turn and compresses the new charge ready for ignition. The disadvantages of this cycle are that the burnt gases are not scavenged completely from the cylinder and the charge of fresh mixture is reduced accordingly.

Four-stroke Cycle

In this cycle of operations there is only one power stroke in every four. The four strokes are :—

Induction Stroke

The piston descends in the cylinder from top dead centre (T.D.C.) to bottom dead centre (B.D.C.) and draws a combustible mixture into the cylinder through the open inlet valve aperture. The exhaust valve is closed during this stroke while the inlet valve remains open until the piston is about one quarter up the cylinder again on the next stroke. The closing of the inlet valve is delayed because the inertia of the incoming charge results in it continuing to flow into the cylinder after the piston has passed B.D.C.

Compression Stroke

With both valves closed the piston ascends and compresses the charge,

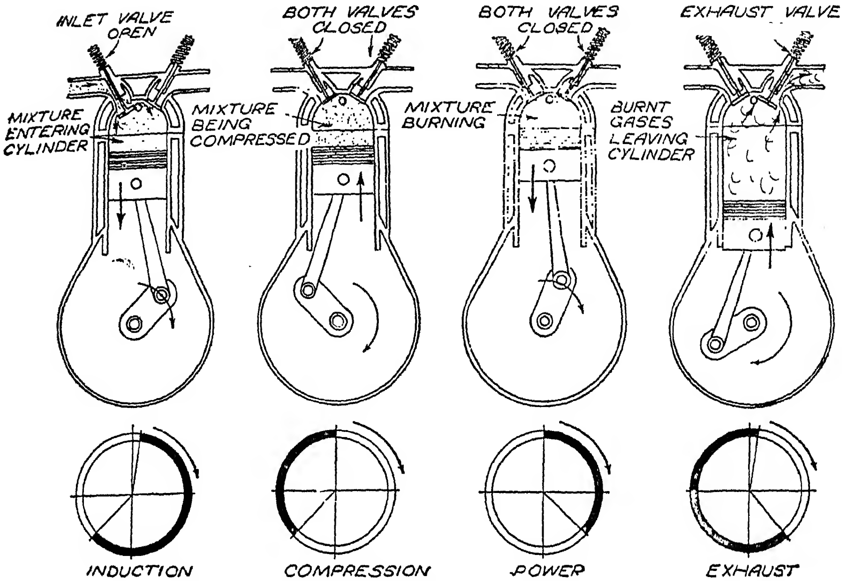


Fig. 2.—FOUR-STROKE CYCLE OF OPERATIONS.

and when it reaches a certain point before T.D.C. a spark at the plug ignites the compressed mixture and combustion takes place. The ignition is set before T.D.C. because it takes a little time for complete combustion of the mixture after the spark occurs.

Power Stroke

The expanding gases exert a high pressure and force the piston down the cylinder from T.D.C. to B.D.C. Both valves remain closed until the piston is approximately three-quarters down the cylinder, when the exhaust valve opens. The reason for this apparently premature opening of the valve is to allow the burnt gases to commence to exhaust under their own pressure and thus relieve the engine from having to force them out. This tends to keep the engine cooler as the hot gases do not remain in contact with the cylinder wall for so long as would otherwise occur. Owing to the angularity of the connecting rod to the web of the crankshaft, the leverage on the crankshaft is very small when the piston is one-quarter of its stroke from B.D.C.

Exhaust Stroke

The piston ascends with the exhaust valve open and the inlet valve closed and expels the burnt gases from the cylinder. The exhaust valve closes at or about T.D.C.

This completes the four-stroke cycle of operations, the crankshaft having travelled through two revolutions. In some cases the inlet valve

opens before the exhaust valve closes, because the outgoing exhaust gases create a slight suction on the inlet aperture which assists in starting the incoming charge to flow into the cylinder.

Types of Engines

Modern aeroplane engines are all of the stationary type, rotary engines having been abandoned owing to their mechanical and volumetric inefficiency.

Stationary engines are either air or liquid cooled, and are further categorised according to the disposition of their cylinders as follows :—

Category	*Type*
"Vertical"	Gipsy I.
"Vertical" inverted type	Gipsy III Major.
	Gipsy VI–2.
"V" type	Kestrel.
	Merlin.
"V" type inverted	Gipsy XII.
"W" type	Lion.
"H" type	Dagger.
	Rapier.
Radial single rows	Cheetah.
	Genet.
	Jupiter.
	Lynx.
	Mercury.
	Niagara.
	Pegasus.
	Perseus.
Radial double rows	Panther II.A.
	Serval.
	Tiger.

Vertical Types

The cylinders, which may be air or liquid cooled, are arranged in a straight line on the crankcase. This type is usually heavier per horse power than other types, but has the advantage of less resistance to the airstream, due to the ease with which it can be streamlined.

"V" Type

In this type the cylinders are arranged in two rows on the crankcase, forming a V ; the angle between the two rows of cylinders varies according to design. By fitting two connecting-rods on each crank pin the two rows of cylinders can be opposed, that is directly opposite each other. This arrangement results in a light, sturdy and powerful engine particularly adaptable to aeroplanes.

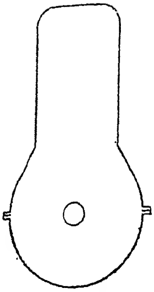


Fig. 3.—VERTICAL TYPE CYLINDER.

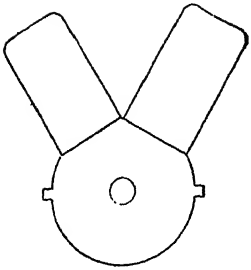


Fig. 4.—" V " TYPE CYLINDERS.

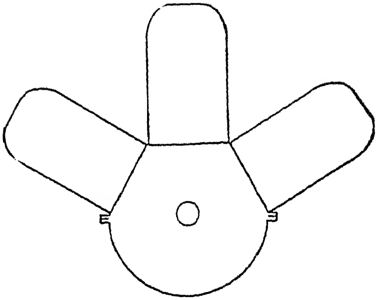


Fig. 5.—" W " TYPE CYLINDERS.

" W " Type

The general arrangement of this type is similar to that of the " V " type, but it has three rows or banks of cylinders. " W "-type engines can be made slightly lighter per horse power than the " V " type.

" H " Type

This may be looked upon as two separate engines of the horizontally opposed type, coupled in tandem, that is, each engine has a cylinder at 180° to an opposing cylinder and connected together by gears which drive the airscrew shaft.

Radial Types

The cylinders in radial engines are equally spaced around the crank-

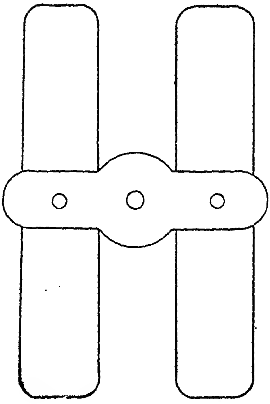
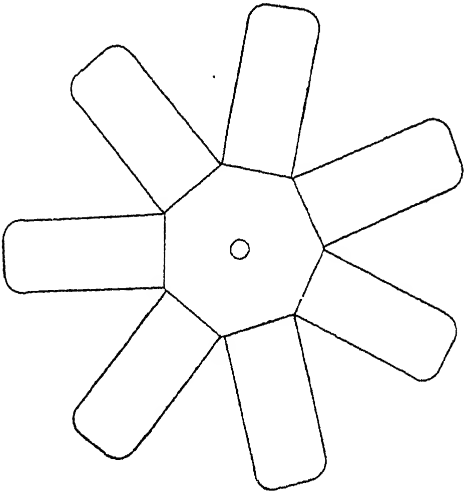


Fig. 6.—" H " TYPE CYLINDERS.



. 7.—RADIAL 7 CYLINDER TYPE.

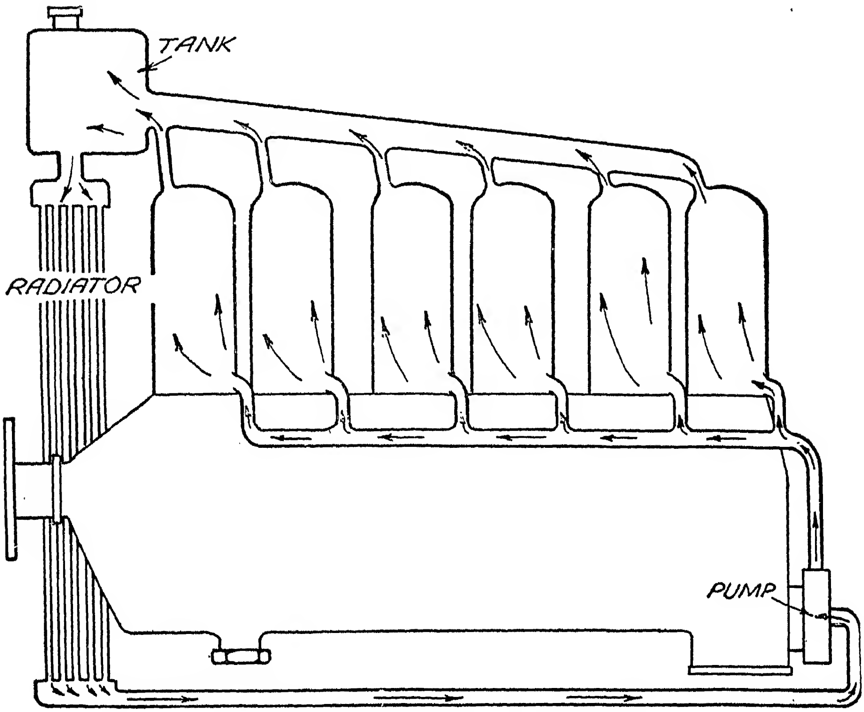


Fig. 8.—TYPICAL LIQUID COOLING SYSTEM.

case, in the same circular plane in a single-row engine. In a double-row radial the rear cylinders are placed between the front cylinders and in the rear of them. Radial engines are air-cooled and have the advantage of being of low weight and high horse-power ratio. Their disadvantage is head resistance, owing to the large frontal area, to the forward motion of the aeroplane.

Liquid-cooling (Conventional Type)

The cylinders of liquid-cooled engines are constructed so that the liquid can circulate through a chamber or jacket round the cylinders. The circulation may be obtained by thermo-syphon, but in aero engine practice it is assisted by a pump. The heated liquid from the cylinders is kept in constant circulation through the engine and into a radiator, where it is cooled. Radiators are constructed in such a manner as to distribute the heated liquid over a large area and to allow cool air to flow through and over tubes to dissipate the heat, so enabling a given quantity of liquid to be used continually.

A controllable shutter fitted in front of the radiator permits the amount of air passing through to be regulated and thus control the tem-

perature of the liquid. The rate at which the heated liquid passes through the radiator for cooling is an important factor. The faster a liquid is passed over a heated surface the faster the rate of transfer of heat will be up to a certain velocity of flow of liquid. Above a certain rate of flow of liquid the rate of transfer of heat does not increase because the hot liquid does not remain in contact with the cooling surface long enough to cool it. On the other hand, the faster the circulation the less liquid will be required, and the weight of liquid can be reduced accordingly, which is of importance in aeroplanes.

Advantages of Liquid-cooled Engines

Liquid-cooled engines have the advantage over air-cooled engines in that they can be cowled and streamlined more easily. Their head resistance can be reduced and better flying performance obtained.

Evaporative Cooling

The conventional type of liquid-cooled engine dissipates heat by raising the temperature of the liquid, this temperature always being kept below boiling point. If the heat generated in the cylinder can be absorbed by the heat required for vaporisation of water, certain advantages would be gained. In the evaporative cooling system some of the water is allowed to boil in the cylinder jackets from the heated surfaces and passes from the engine in the form of steam to a steam separator. The condensed water is returned to the cylinder jacket without passing through a radiator, while the steam is cooled to water in an air-cooled condenser and then returned to the cylinder jacket.

Advantages of Evaporative Cooling

The advantages of this system are :—

(*a*) The weight of water required is about one-third of that required for equally efficient cooling on the conventional liquid-cooled system.

(*b*) The necessary surface area of the condenser is smaller than the normal radiator because the temperature difference between that of the steam and the air is so much greater.

(*c*) The cylinder wall temperature is higher and there is therefore less frictional loss.

(*d*) The heat is retained for a longer period when the aeroplane is gliding, as the steam only is cooled and the circulating water is not.

There is a disadvantage in (*c*) in that the higher temperature results in a lower volumetric efficiency and a greater heat loss by radiation.

Air-cooling

The rate of cooling of an air-cooled engine depends on the area of the metal from which the heat is dissipated. This factor is, therefore, of importance in the cooling of engines directly by air. Fins are fitted in

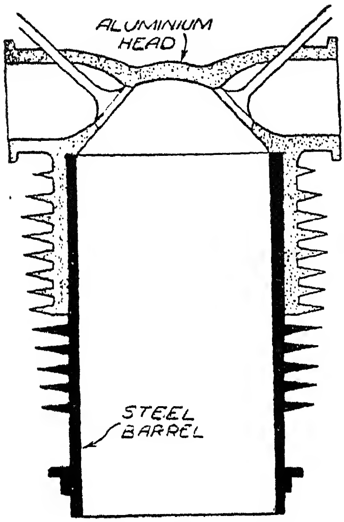


Fig. 9.—TYPICAL AIR-COOLED CYLINDER.

order to increase the heat-dissipating area, particularly on the cylinder head, where the greatest amount of heat is generated. The rate of cooling also depends upon the volume and conductivity of the metal through which the heat is conducted to the area cooled by the air. For this reason the cylinder head is usually made relatively heavy and, in many cases, made of aluminium alloy, which has a very high conductivity. The rate of cooling is, of course, also dependent on the rate at which the cooling air passes over the cooling fins and upon the temperature of the air. In air-cooled aero engines the cylinders are exposed to the air stream, which controls cylinder temperatures, and such engines may be fitted with suitable cowlings and shutters, which regulate the amount of air flowing past the cylinders with a view to the maintenance of an even temperature, particularly where extremely hot or cold weather conditions have to be considered.

Advantages of Air-cooled Engines

Air-cooled engines have the advantage over liquid-cooled in that their weight per horse-power is lower, they are more reliable in extreme hot or cold weather and less susceptible to extreme high altitude conditions. They are also less liable to damage by gun fire in military aeroplanes by virtue of the fact that they are not dependent upon a vulnerable cooling system.

Heat Balance

The heat or thermal efficiency of an engine is the percentage of the total amount of heat generated by combustion of the fuel which the engine delivers in the form of work. The amount of heat energy actually converted into useful work is only about 25 per cent. of the total heat energy of combustion in a well-designed engine. The remaining 75 per cent. is lost. The heat balanced is approximately as follows :—

Heat converted into work . . .	25	per cent.
Exhaust losses	40	,,
Cooling losses	27	,,
Radiation losses	4	,,
Frictional losses	4	,,
	100	

Exhaust Losses

If the end of the power stroke in a four-stroke engine occurred at B.D.C. instead of about one-quarter of the stroke before B.D.C., less heat would be lost in the exhaust, but tests have shown that the heat thus conserved does not increase the power output, that is, the heat efficiency. On the contrary, the engine loses power as a result of the hot gases remaining longer in the cylinder. The cylinders get much hotter and more heat is lost in cooling, radiation and conduction than is saved in the exhaust. If, however, the exhaust valve were opened at a very early point in the power stroke the excess of heat then lost in the exhaust would of course exceed the heat saved in cooling, radiation and conduction.

Cooling Losses

The means described for cooling by air or liquids are provided because heat obviously cannot be generated continuously in a closed cylinder without adequate means for control of its temperature. The highest practicable rate of cooling is desirable. The rate of cooling is as stated previously, dependent upon the area of the metal exposed to cooling, its conductivity and volume and upon the temperature difference between the area to be cooled and the cooling medium.

Frictional Losses

Power is required to overcome the friction of the moving parts, as well as the energy required to draw in and expel the gases. These losses can be minimised by improvement in design and construction.

Radiation Losses

Heat passes from the cylinders by conduction through the metal parts of the engine and by direct radiation as radiant heat. This heat loss can be considered as separate from the heat lost to the cooling medium.

The loss by conduction and radiation depends on the thickness of the metal through which the heat has to travel, as well as upon its conductivity. The use of a metal of high conductivity reduces the heat lost by cooling slightly, but increases the heat lost by conduction and radiation considerably and tends to distribute it throughout the engine.

Lubrication

Resistance or friction is offered by one dry metal moving over another and results in excessive wear. If a suitable lubricant is introduced between the moving surfaces the friction and wear on the metal is practically negligible. One cannot, however, eliminate the viscous friction of the lubricant. For convenience, friction may be categorised as ball bearings, rolling and sliding friction. Ball bearings require the least amount of lubrication, while rolling friction, as met with in roller bearings, require less lubrication than sliding surfaces such as those in main bearings.

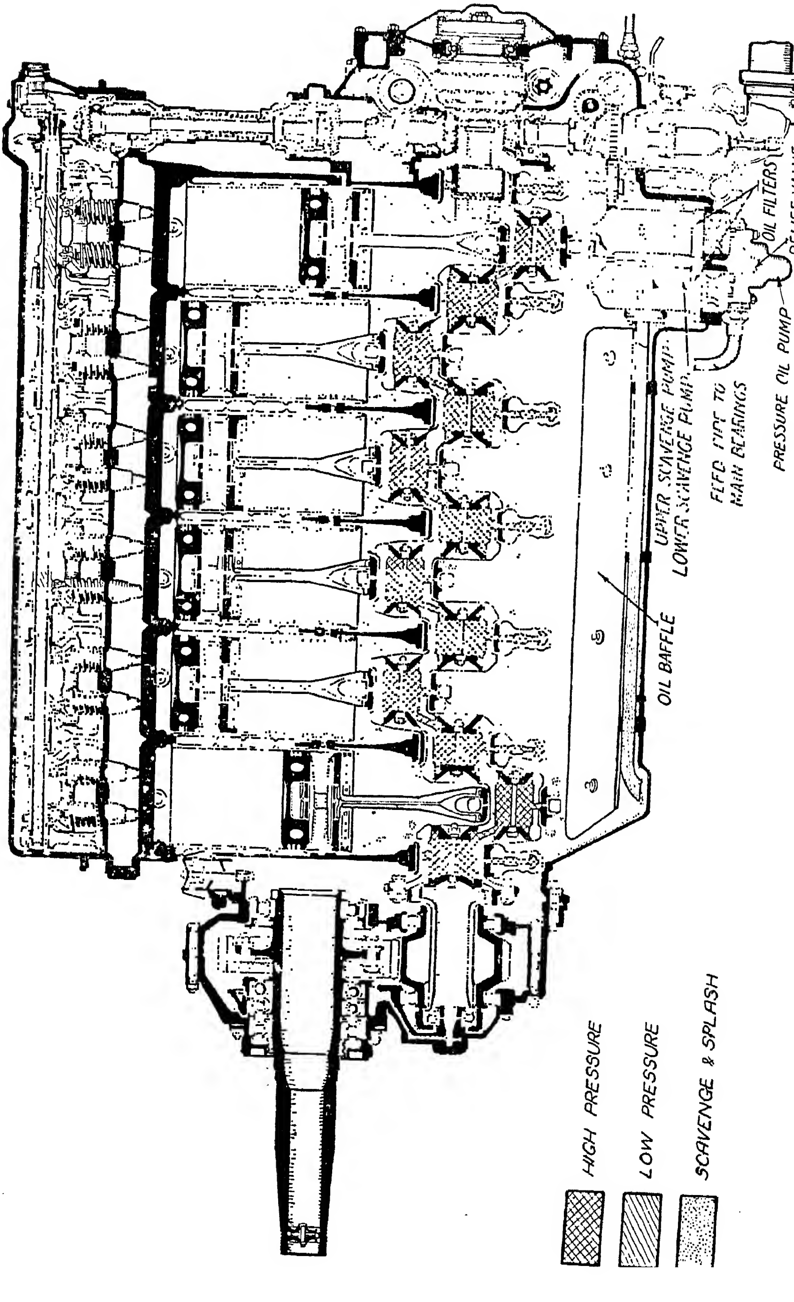


Fig. 10.—TYPICAL PRESSURE LUBRICATING SYSTEM.

Lubrication of Internal Combustion Engines

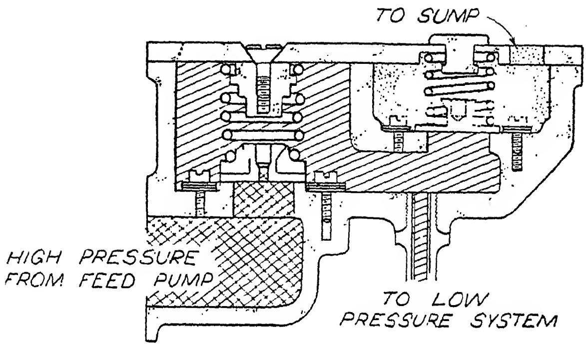


Fig. 11.—TYPICAL RELIEF VALVE ARRANGEMENT.

Several problems present themselves in designing an efficient lubricating system for an internal combustion engine due mainly to the high temperatures and varying pressures to which the lubricant is subjected. At high temperatures the lubricant thins out and may lose its lubricating properties. In some aero engines, arrangements are made to cool it by passing it through a radiator; in others very large quantities of the lubricant are passed through the bearing surfaces. In order to maintain a film of lubricant under varying loads, the lubricant must be maintained at a sufficiently high pressure to furnish a constant supply to all working parts. For this reason aeroplane engines are therefore normally lubricated by a high-pressure system.

The splash system of lubrication is unsuitable for aero engines because some parts of the engine might be starved during aerobatics.

Pressure System of Lubrication

In this system the lubricant is forced under pressure to the various parts of the engine by a mechanical pump. A small amount is allowed to drain out of the main bearings and is thrown on to the piston and cylinder walls. A pressure gauge is located in the pipe line between the pump and the main bearings. A relief valve is incorporated in order to maintain the pressure at a predetermined value. In aero engine practice the lubricant is normally contained in a separate tank and not in the crankcase as in motor-car engines. This system is known as the dry sump system. The lubricant which drains from the various parts of the engine is returned to the tank by a second mechanical pump, called the scavenge pump. This scavenge pump is of larger capacity than the pressure supply pump. The reason for this is that when an aeroplane is climbing or gliding steeply the lubricant would flow to one end of the crankcase. If this happens there is a possibility that too much oil will be splashed into the lowest cylinder. This would be liable to oil up the plug or plugs and result in misfiring.

General Outline of Dry Sump System

Practically all aero engines employ the dry sump pressure lubrication

system, in which the lubricant is supplied under pressure to the main bearings, camshaft, gudgeon pins and auxiliaries. The pressure and scavenge pumps are mechanical. They are generally of the gear-wheel type and in the majority of engines are located in the same casing and driven by a common drive shaft. The lubricant is drawn from a tank by the pressure pump through a fine gauze to remove any foreign matter before it enters the pump.

The pressure pump delivers the lubricant to the main bearings by pipes which branch off a common delivery gallery. The crankshaft is hollow and is drilled to allow the lubricant to enter the journals when the holes in the bearings and journals line up with each other in each revolution of the crankshaft. The lubricant is carried by pressure assisted by the centrifugal force resulting from the rotation of the crankshaft through holes drilled in the crank webs, to the big-end journals to lubricate the big ends of the connecting rods. The lubricant which escapes from the main and big end bearings is thrown on to the cylinder walls in the form of mist which lubricates the piston, piston rings, gudgeon pins and cylinder walls. The camshaft is generally lubricated by a separate pipe system from the main pressure pump. This supply pipe is usually located at the airscrew end of the engine and lubricates the camshaft bearings, cams, rocker levers, etc. The lubricant on its return to the scavenge pump oils the camshaft drives. A pressure relief valve is incorporated in the pressure pipe between the pump and main bearings. This valve is adjustable and controls the pressure at which the lubricant is delivered to the main bearings; any excess oil is returned from the relief valve to the sump and extracted by the scavenge pump. The scavenge pump extracts the oil from the sump, which is usually designed to have two depressions or pits, one at the front and the other at the rear of the crankcase. The lubricant cannot therefore collect in large quantities at either end. In some cases the thrust bearing is oiled by a special supply from the pressure feed, in others external cups filled by hand.

Construction of Engine Details

Reliability is of primary importance in the design and construction of the working parts of internal combustion engines. The parts must be strong and light, but primarily they must be reliable. Every detail must be carefully examined, in order to obtain a unit which is :—

(*a*) Of clean design.
(*b*) Reliable in operation.
(*c*) Of low weight per horse-power.
(*d*) Economical in oil consumption.
(*e*) Economical in fuel consumption.
(*f*) Free from vibration.

Cylinders

This is the part in which the power is developed to accomplish the

work. The type of cylinder used almost exclusively in aero engines consists of a steel barrel or sleeve, which acts as a guide for the moving piston. The cylinder head may be either integral with the cylinder barrel, or manufactured separately and secured to the upper end of the barrel. The head forms the combustion chamber. The inlet and exhaust valves are fitted in this with their respective ports for the gases to enter and leave. In liquid-cooled engines a compartment or jacket is built around the cylinder barrel and head. In the air-cooled engine radiating fins are machined round them. The cylinder has a machined base integral with it to fix it to the crankcase. The design of the combustion head is as near hemispherical in shape as possible. This shape minimises the heat loss and allows direct flow of the incoming and outgoing gases. This type of cylinder requires a more complicated valve mechanism than that required by types such as the L- and T-shaped cylinders which are generally used in motor-car engines.

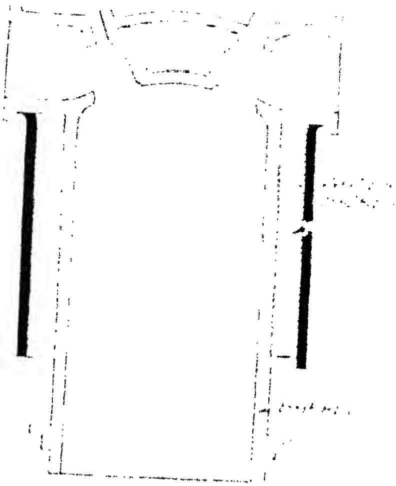


Fig. 12. WATER-COOLED CYLINDER.

Valves, Valve Springs and Guides

A valve is a means of opening and closing a port in order to admit fresh gases into the cylinder and to allow burnt gases to escape. The poppet type of valve is generally employed for aero engine work, although some of the most recent engines such as the Perseus are of the sleeve valve type. This type of engine is described elsewhere. The head of a poppet valve, which opens and closes the port, has a round and bevelled edge called the valve face, which rests on the bevelled valve seat in the cylinder head when the valve is closed. The valve stem works in a guide, which locates it in the cylinder head. Such poppet valves are operated by mechanical means and they are closed by the valve springs. It is usual in aero engine practice to fit valve springs in duplicate for safety in case one breaks. The duplicate valve springs are coiled in opposite directions to equalise the pressures on the valve stem. They are held in position over the valve stem and kept in place by a locking device. The valve guides are usually made of cast iron or phosphor bronze. The valve stem must be a good fit in its guide, slackness between the inlet valve stem and the guide allows air to be drawn into the cylinder, resulting in a weak mixture.

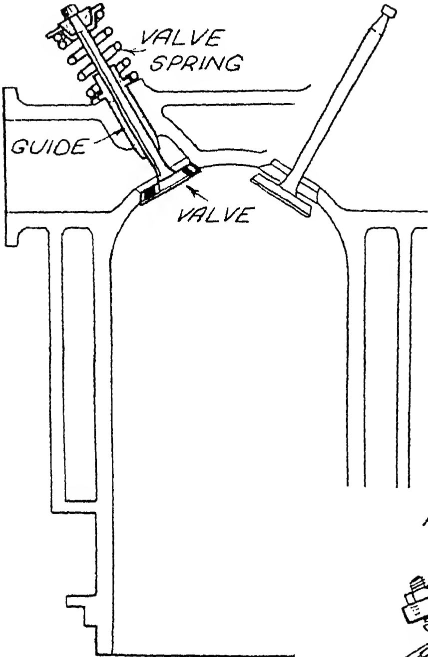


Fig. 13. — CYLINDER ASSEMBLY SHOWING VALVE SPRING AND GUIDE.

Valve Rocker Arms

These are usually manufactured from good-class steel forgings and are supported at their centres by a small bearing, one end rests on the cam or is operated by a rod from the cam. The other end of the rocker arm operates the valve and is fitted with means for adjusting the clearance between the valve stem and rocker arm.

Piston

The piston is the component which works up and down in the cylinder. It acts as a plunger for drawing the mixture into the cylinder, compressing it, imparting the force of the expansion of the burning mixture to the crankshaft by means of a connecting rod and expelling the burnt gases. In aero engines the piston is usually made of aluminium alloy to combine lightness with strength. Its lightness reduces operating stresses, and aluminium being a good conductor of heat, the heat of combustion is

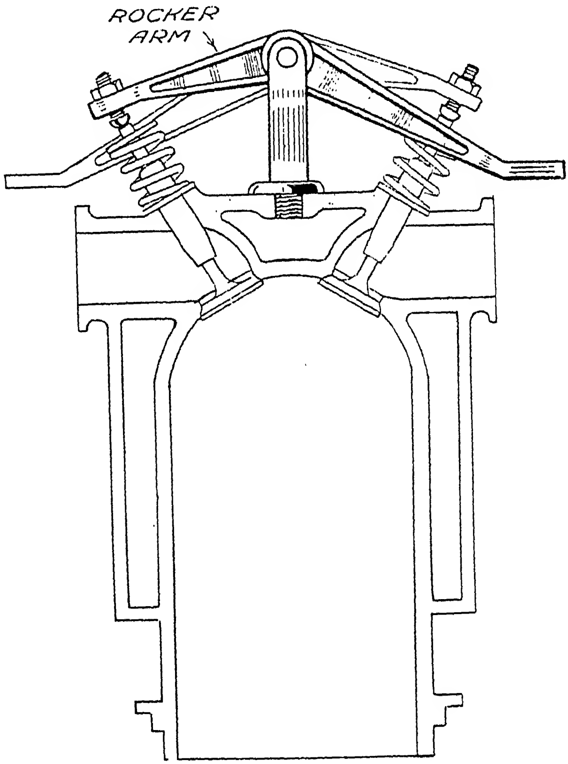


Fig. 14.—CYLINDER ASSEMBLY SHOWING ROCKER ARM.

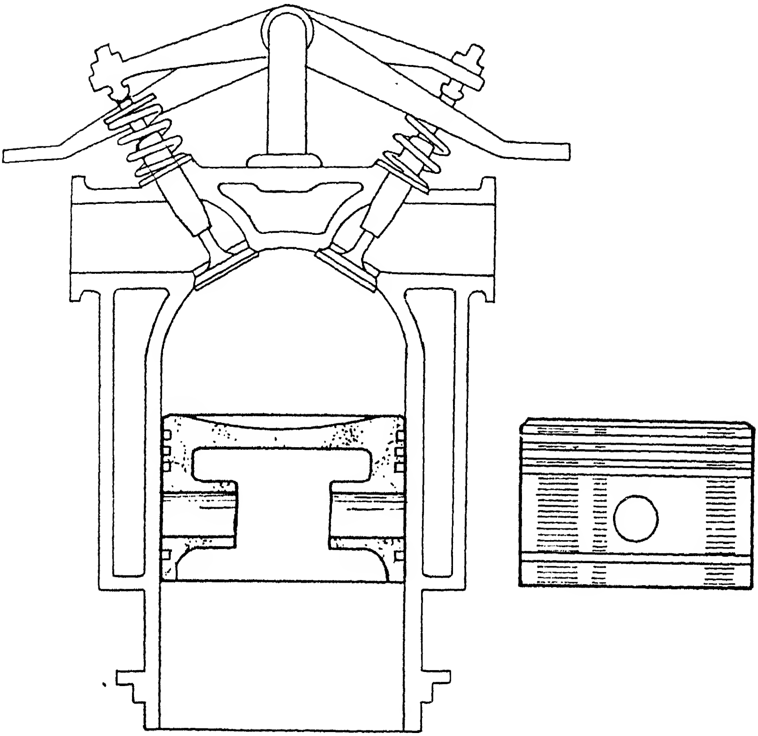


Fig. 15.—CYLINDER ASSEMBLY SHOWING PISTON.

conducted rapidly away from the piston head to the cylinder wall. Low piston-operating temperatures are thus obtained, which results in less heat being transferred to the next incoming charge; the volumetric efficiency of the engine is thus increased, which in turn permits of a high compression ratio without causing detonation.

Piston Rings

Piston rings are fitted on a piston to prevent leakage of the burning gases from the combustion chamber, and also to prevent a large amount of oil getting in the combustion chamber from the crankcase. These piston rings are fitted into grooves which hold them true to the cylinder wall. They are normally made of a good cast iron and are capable of exerting pressure on the cylinder walls, sufficient to prevent the loss of pressure and entry of oil referred to above, and that without an undue amount of friction. In aero engine practice piston rings are concentric and have a gap cut in them during manufacture. This gap may be either diagonally across or it may be stepped. The leakage of gas or oil past

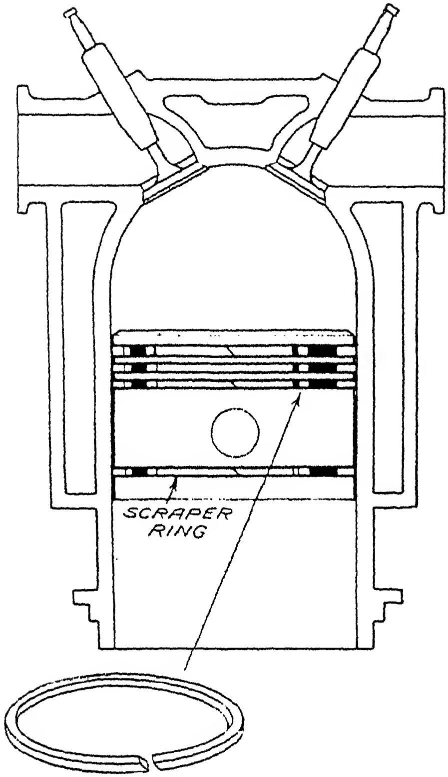


Fig. 16.—Cylinder assembly showing piston rings.

the gap, whether diagonal or stepped, is so small that the diagonal cut is used in the majority of aero engines because it is easier to cut. Two or three rings are normally fitted at the top of each piston.

Scraper Rings

A scraper ring is fitted at the lower part, or skirt, of the piston. This scraper ring is fitted in a groove in the same manner and is of the same material as the piston rings. Its object is to prevent an excess of oil getting up between the piston and the cylinder wall, which might eventually pass the piston rings to the combustion chamber, where part of it would burn and deposit carbon in the combustion chamber. The fitting of a scraper ring is not universal in internal combustion engine practice.

Gudgeon Pins

The gudgeon pin is the means of connecting the piston to the connecting rod. It is generally made of a nickel steel alloy which is casehardened and ground. It thus possesses a hard, durable surface and a tough core capable of withstanding the severe sheering stresses to which it is subjected. The gudgeon pin is, in the majority of cases, made hollow, in order that it may have as large a bearing surface as practicable and be as light as possible for the strength required. Gudgeon pins may be either fixed in the piston bosses or floating in both the piston bosses and connecting rod small end. When fixed they are secured by locking plates and bolts; when floating the pin is usually held in position by circlips, which prevent it from protruding and scoring the cylinder walls.

Connecting Rods

The piston assembly is joined to the crankshaft by a connecting rod. This connecting rod transmits the reciprocating motion of the piston to the crankshaft, where it is converted into rotary motion. Connecting rods are made of alloy steel of high tensile strength.

They are classified according to their shape and method of fitting to the crankshaft. They vary also in cross section, and are either I, H or tubular. The bearing arrangements on the crankshaft are generally one of the following three types: plain, articulated or forked.

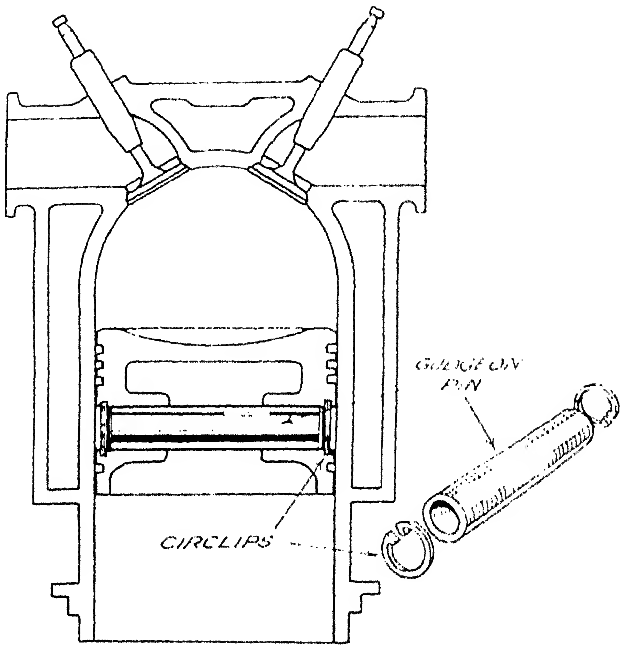


Fig. 17.—Cylinder assembly showing gudgeon pin.

The small end, or the bearing on the gudgeon pin, is fitted with a phosphor bronze bush, because the melting point of this material is high and will withstand the heat generated at the piston head. The big end is in two halves, which are held together by bolts. The halves are lined with an anti-friction metal which may either be cast directly on to the housings or on to split steel or phosphor bronze shells or bushes.

Plain Type Connecting Rod

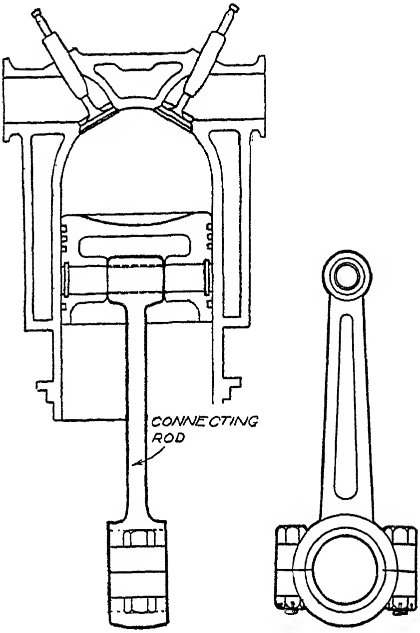
The plain type connecting rod is a single rod and is seldom used in high-powered aero engines. If this type of rod were used in " V " or " W " engines two rods would require to be fitted side by side on the same crankpin; this would require the cylinders to be staggered on the crankcase and add weight and length to the engine.

Articulated Type Connecting Rod

This type is employed on " V," " W " and radial engines. It consists of a master connecting rod with one or more shorter rods attached to its big end by wrist pins; these pins operate in phosphor bronze brushes. This arrangement permits the construction of a light and short engine, without sacrifice of reliability.

Forked Type Connecting Rod

This type is employed on " V " engines, and consists of two rods



operating on the same crankpin, one rod being of the plain type, the other forked. There are two methods of construction. In one the forked rod carries the crankpin bearing and the plain rod operates on the outside of this bearing; in the other the plain rod carries the crankpin bearing and the forked rod straddles the plain rod and operates on the outsides of the bearing. The difficulty of adjusting the bearings is a disadvantage of this type of connecting rod.

Crankshafts

This is the part which converts the reciprocating motion received from the power exerted on the piston into rotary motion and in aero engines delivers it to the air-screw. The crankshaft is generally

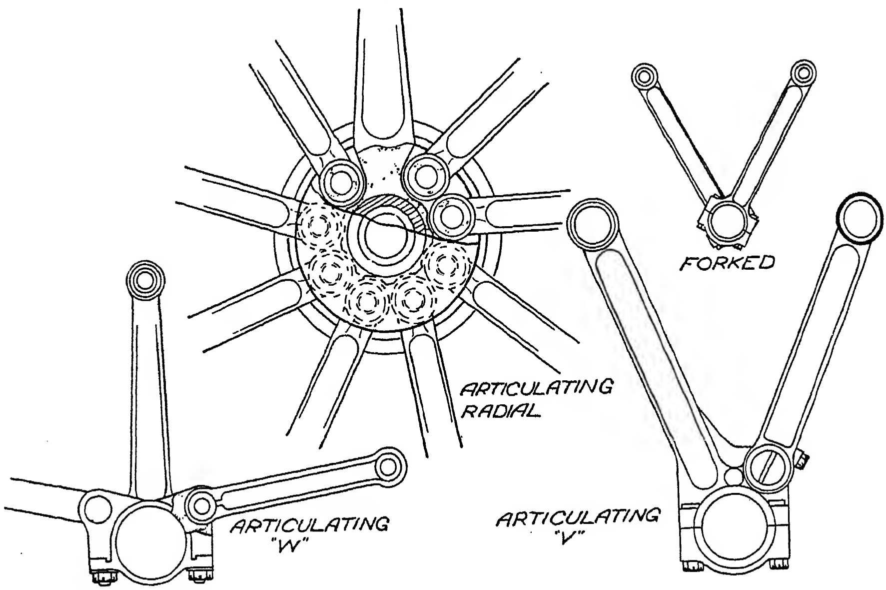


Fig. 18.—CYLINDER ASSEMBLY SHOWING CONNECTING ROD.
Showing also various types of connecting rods.

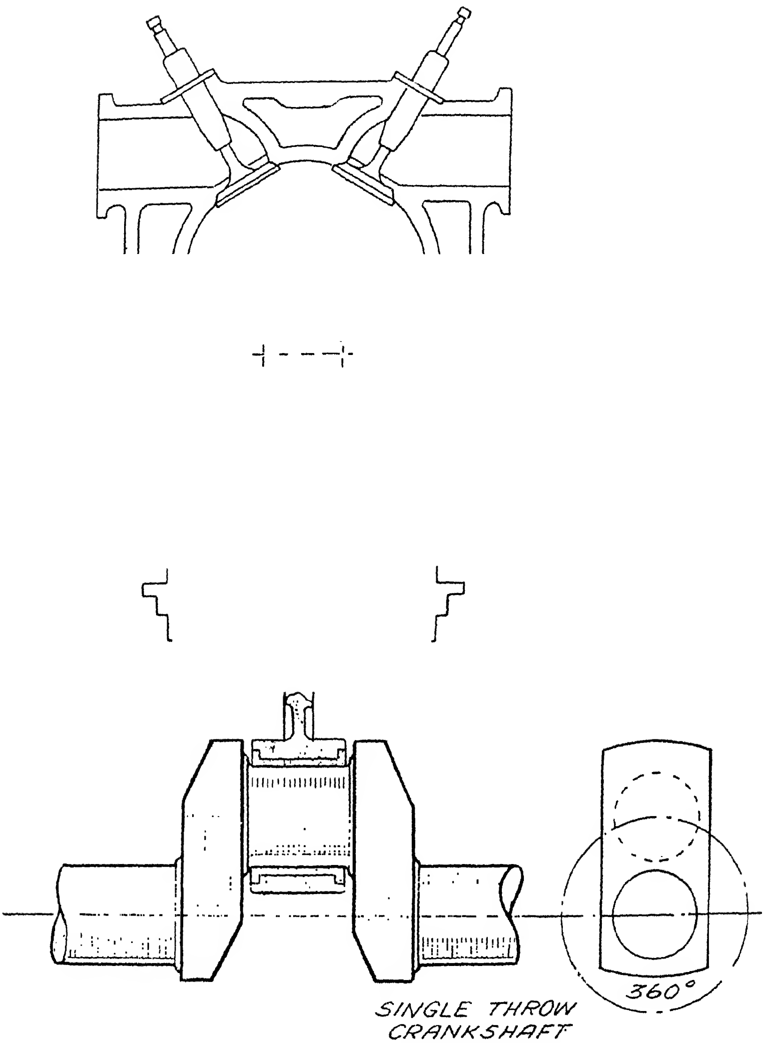


Fig. 19A.—CYLINDER ASSEMBLY SHOWING CRANKSHAFT.

machined from a forging of alloy steel of high tensile strength. It revolves in main bearings which are carried in the crankcase. Crankshafts are normally classified by the number of crankpins or throws and the angle between the throws. The number of throws is dependent on the number of connecting rod assemblies. The most commonly used types of crankshaft are the 360°, 180° and 120° types. The part which rotates in the main bearing is known as the crankshaft journal. The crankpins carry the

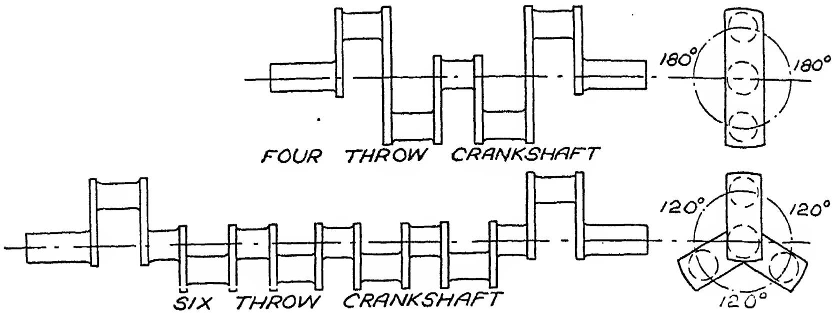


Fig. 19B.—SHOWING TWO TYPES OF CRANKSHAFT.

connecting rod and the crankshaft webs connect the journals to the pins. The distance between the centres of the journal and pin is dependent upon the length of the stroke of the engine. In aero engine practice the crank journals and pins are bored for lubrication purposes and the bores sealed. The communication between them is by ducts drilled in the webs.

360° *Type Crankshafts*

This type is known as the single throw crankshaft and is generally employed in radial engines. It may be constructed in one solid piece or in two parts. The two-piece crankshaft allows ball bearings to be used for the connecting rod big ends, which reduces friction. The one-piece crankshaft is desirable for strength, but necessitates the use of a plain connecting rod bearing.

180° *Type Crankshafts*

This type has two or four throws, each throw being 180° apart. In radial engines with two banks of cylinders the two-throw 180°-type is usual, whilst in the four-cylinder vertical and the eight-cylinder " V " engines the four-throw 180°-type is used. In the latter case two connecting rods are fitted to each crankpin.

120° *Type Crankshafts*

This is the generally accepted type for six-cylinder vertical and twelve-cylinder " V " engines. The six-throw 120°-type crankshaft necessitates two connecting rods to each crankpin in the case of the twelve-cylinder " V " engine.

Thrust Bearings

An aero engine crankshaft must incorporate some method of counteracting the thrusts of the airscrew; these are taken by thrust bearings. They may be of either the single row, deep groove, heavy type, or of the

double row, double direction, flat-face type. The annular type is not adjustable and only takes thrust in one direction, whereas the thrust-ball type is adjustable for wear and takes thrust in both directions. The thrust bearing in general use in aero engines is at the airscrew end of the crankshaft and is generally of the annular or thrust-ball type.

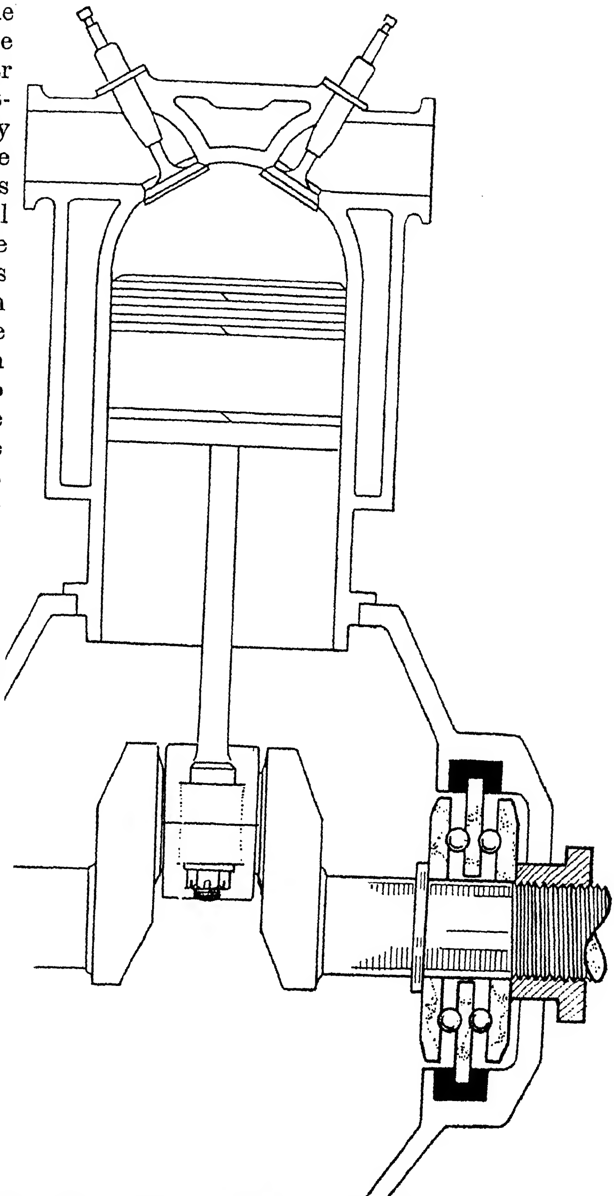


Fig. 20A.—Cylinder assembly with double row thrust bearing.

Main Bearings

The main bearings hold the crankshaft in place and take the loads and reduce, as far as is practicable, metallic friction to a minimum. They are normally classified into three groups:—

(a) Plain.
(b) Ball.
(c) Roller.

Plain Bearings

Plain bearings are most commonly used owing to their reliability and the ease with which they can be adjusted. They are generally employed as main, connecting rod big end, camshaft and auxiliary

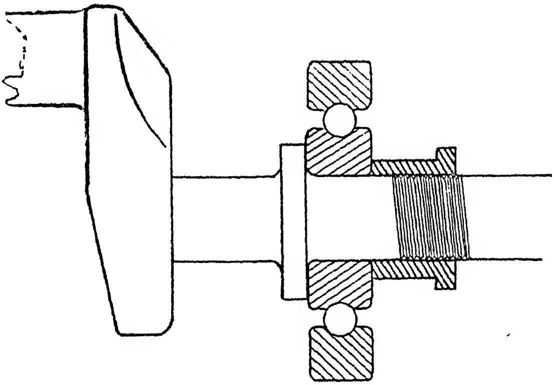


Fig. 20B.—DETAIL OF SINGLE ROW THRUST BEARING.

bearings, and are usually constructed in two parts, fastened together by bolts or studs. The bearing surface is of an anti-friction, non-ferrous metal, such as white metal, babbitt metal, brass or bronze or a combination of these metals. Where high speed or heavy duty is called for the anti-friction metal is usually backed by bronze or steel to strengthen the bearing. For slow-speed work and light duty, such as camshaft bearings, plain bearings of brass, bronze or aluminium are satisfactory.

Ball Bearings

These are normally used for thrust bearings and for such engine accessories as magnetos, generators, etc. They are constructed of hardened steel balls operating between an inner and outer ball race or track and are assembled so that the balls cannot fall out of position. Ball bearings require less lubrication than plain bearings, but the highly polished balls are liable to corrode if not in continual use.

Roller Bearings

In radial-type aero engines, roller bearings are sometimes used as main bearings, but in other types of aero engines are only used for accessories. They are more adaptable than ball bearings, due to greater contact surface, but the total friction is greater and they require more lubrication, although friction is less than with plain bearings.

Crankcases

The crankcase is the foundation around and upon which the various parts of the engine are assembled, including such accessories as the starters, generators, etc. Crankcases are normally made of cast aluminium alloy and are webbed for strength. There are various designs, but in normal practice crankcases for vertical and "V"-type engines are made in two parts which are bolted together. In some designs the crankshaft bearings are held in position by bolts passing through both halves of the crankcase, in others the lower half of the crankcase does not house the lower half of the main bearings, but is only a shield covering the internal parts of the engine. Crankcases for radial engines may be designed in three or four parts, certain parts housing the thrust races, rear accessory drive, in addition to the main bearings.

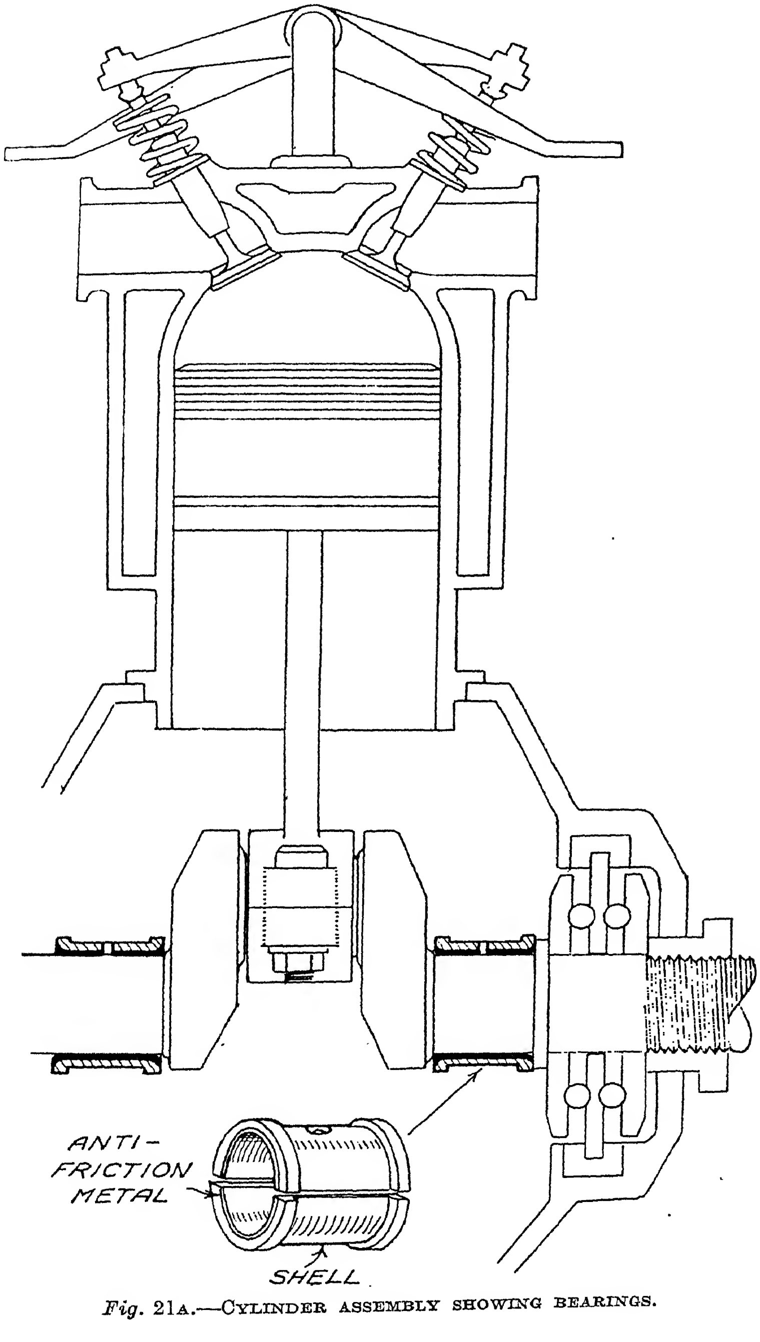


Fig. 21A.—CYLINDER ASSEMBLY SHOWING BEARINGS.

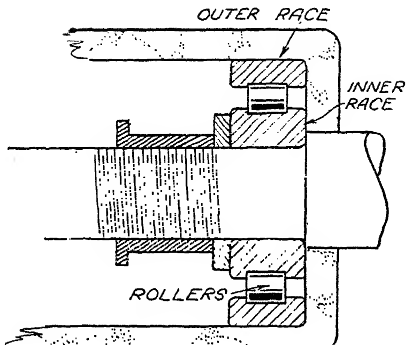


Fig. 21B.—ROLLER BEARING.

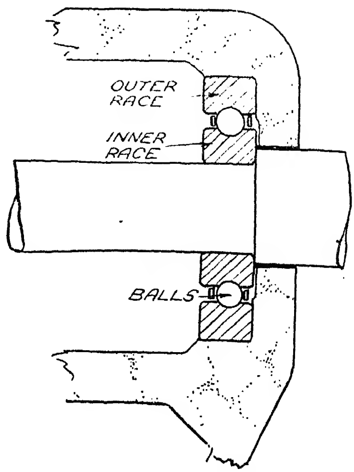


Fig. 21C.—BALL BEARING.

Camshafts and Camrings

Camshafts and camrings are for opening the valves. They are made of case-hardened alloy steel and driven by suitable gearing. The camshafts of vertical, "V" or "W" type engines are similar in design, but for radial-type engines camrings are employed, the cam contours being machined on the outside of an alloy steel ring or disc.

Camshafts

The type camshaft usually used has alternate inlet and exhaust cams, but some aero engines have two separate camshafts, one for the inlet valves and the other for the exhaust valves. Camshafts are driven by gear wheels and drives from the crankshaft. The camshaft either opens the valves by direct contact or by means of rocker arms. The valves, as already stated, are closed by the valve springs. An exhaust cam can usually be distinguished from an inlet cam by its contour; the exhaust cam is slightly wider at the apex, as this valve remains open longer than the inlet valve.

Camrings

Two camrings are used in radial engines, one for the exhaust and one for the inlet valves. Camrings are usually driven indirectly from the crankshaft and the valves are operated by push rods and rocker arms.

Induction Pipes

Induction pipes convey combustible mixture from the carburetter to the various cylinders, and, in addition, act as a fuel-vaporising chamber. They are usually constructed of steel piping and shaped according to the

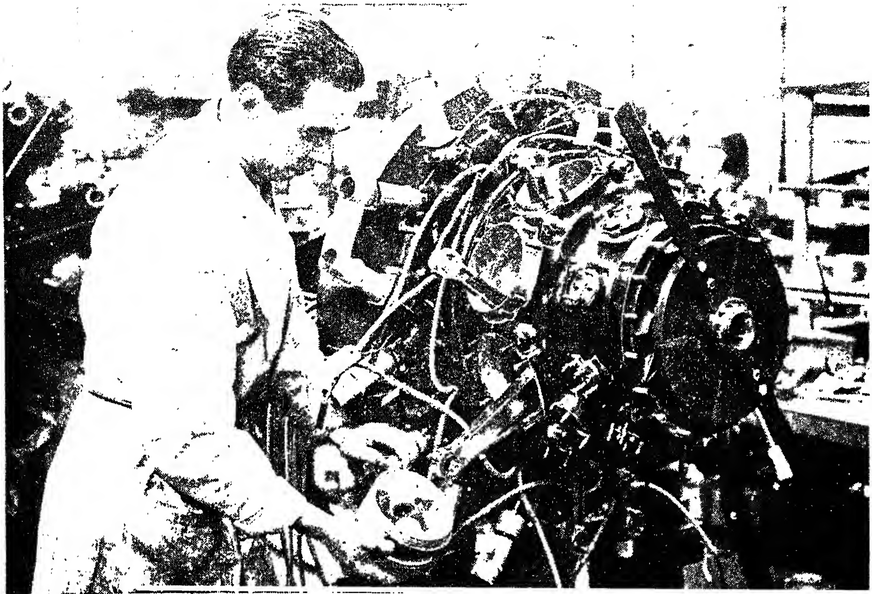


Fig. 22A.—SHOWING CRANKCASE OF RADIAL ENGINE (BRISTOL PEGASUS 10C).
Note the piston and immediately above this the master connecting rod (see also Fig. 18).

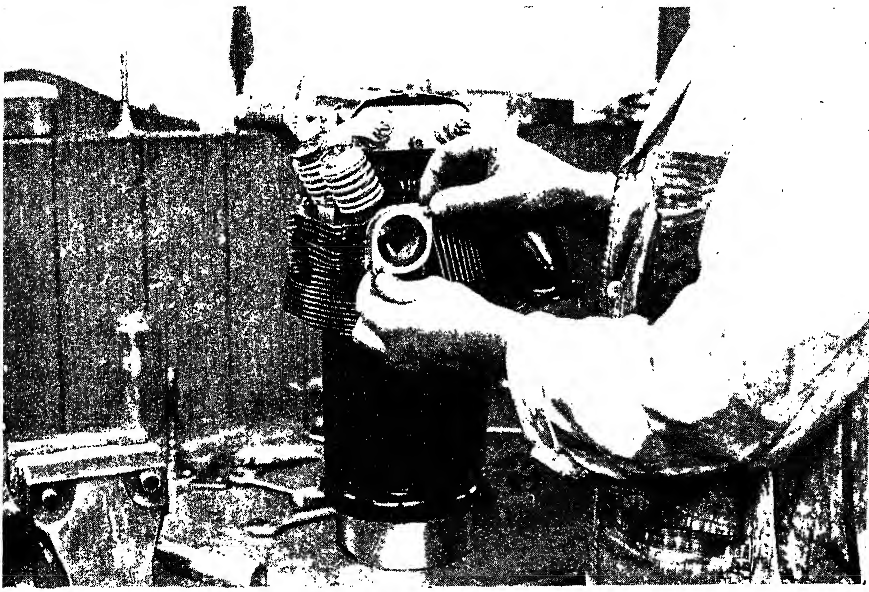


Fig. 22B.—SHOWING ONE OF THE CYLINDERS OF A TYPICAL RADIAL AERO ENGINE (BRISTOL PEGASUS 10C).

[*By courtesy of Imperial Airways Ltd.*

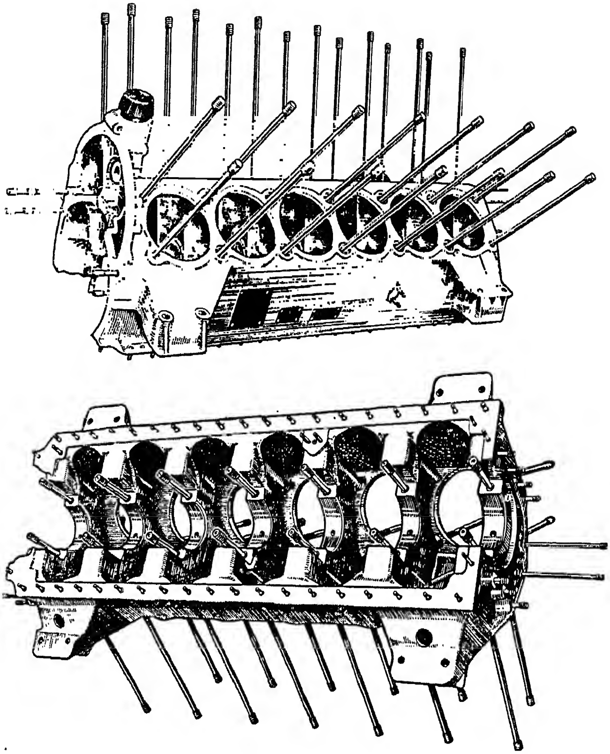


Fig. 22C (*right*).—"V" TYPE ENGINE CRANKCASE, TOP HALF.

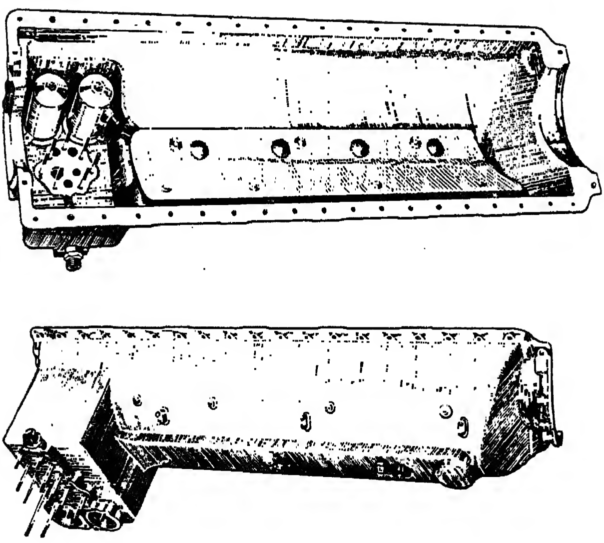


Fig. 22D (*left*).—"V" TYPE ENGINE CRANKCASE, BOTTOM HALF.

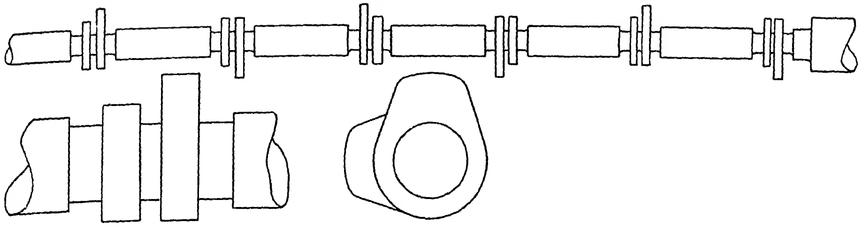


Fig. 23.—ARRANGEMENT OF CAMSHAFT.

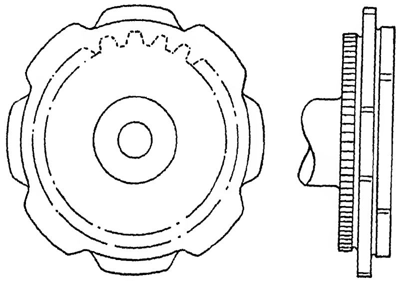


Fig. 24 (*right*).—DETAILS OF CAM RING.

design of the engine. The inside of the induction pipes should be as smooth as possible in order to avoid skin friction, and very sharp bends should be avoided and the pipes kept as symmetrical as possible, so as to prevent any restriction or lack of uniformity of the flow of the mixture entering the cylinders. Induction pipes for liquid-cooled aero engines are normally jacketed and the hot circulating liquid passing through the jackets assists in vaporising the fuel.

Exhaust Manifolds

Exhaust manifolds conduct the burnt gases from the cylinders to the

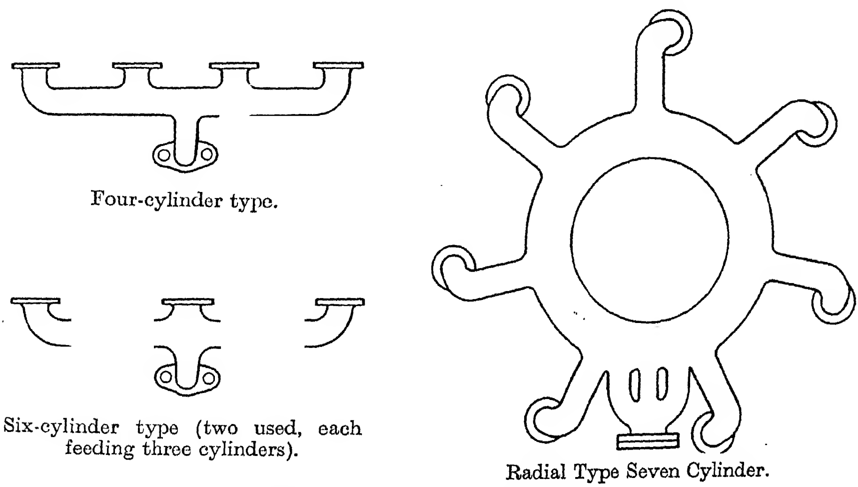


Fig. 25.—TYPES OF INDUCTION PIPES.

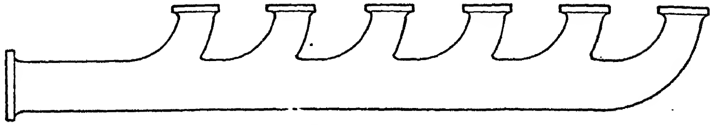


Fig. 26.—EXHAUST MANIFOLD.

atmosphere, and must do so without risk of setting fire to the aeroplane; they must also lead the gases clear of the pilot and passengers. They should be so designed that there is a minimum of back pressure. Short-stub pipes are, from an efficiency aspect, the best, as the back pressure is reduced to a minimum, the exhaust valves and springs are kept cooler by radiation and stub pipes are more easily manufactured. They have the disadvantage, however, that when the aeroplane is sideslipping there is the possibility of the exhaust valves warping when the cold air impinges upon them. This may cause fire besides increasing the back pressure. The usual practice is to connect all the exhaust ports to one long exhaust manifold which conducts the burnt gases away from the airframe. Such manifolds eliminate any possibility of the exhaust valves being warped by the ingress of cold air during aerobatics.

Oil Pumps

The necessary pressure for the lubricating system is obtained by a pump. There are two main types, the plunger pump and the spur gear pump. The latter is the type in general use for aero engines and can be employed either as a pressure or scavenge pump. This pump consists of two exactly similar closely meshed spur gears, one of which is power driven from the crankshaft. The spur gears are enclosed in a casing with a minimum working clearance between the teeth of the gears and the casing. The lubricant enters the inlet side of the casing, is carried round inside the casing by the teeth and delivered under pressure from the outlet side. The teeth of the spur gears revolve towards each other on the outlet side. As a tooth in mesh does not entirely fill the space between the two adjacent teeth of the other spur gear, some oil is carried back from the outlet to the inlet side. This reduces the capacity of such pumps to a slight extent.

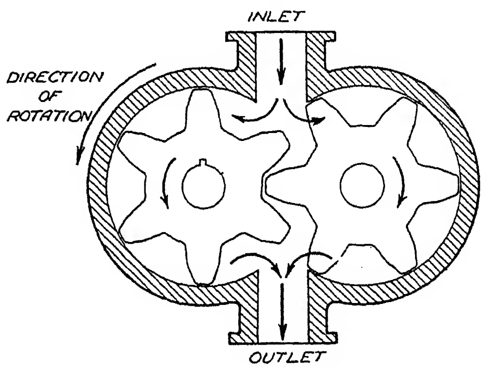


Fig. 27.—SPUR-GEAR OIL PRESSURE PUMP.

Liquid Cooling Circulating Pump

The circulating pump is of the centrifugal type in most liquid-cooled engines. Such pumps consist of a power-

driven impeller, the blades of which may be either curved or straight. The capacity of the pump depends upon the number of blades extending from a common centre, usually between five and ten. The impeller is rotated at a comparatively high speed in a close-fitting housing with an inlet and an outlet port. The inlet port is in the centre of the casing and leads the liquid to the middle of the impeller. The rotating blades of the impeller throw the liquid outwards by centrifugal force and it passes through the outlet ports, which are set at a tangent to the pump casing. Large quantities of liquid can be circulated by such centrifugal pumps, but they are not capable of delivering it at high pressure. Circulation of a large volume of liquid per minute at low pressures is desirable for the cooling system.

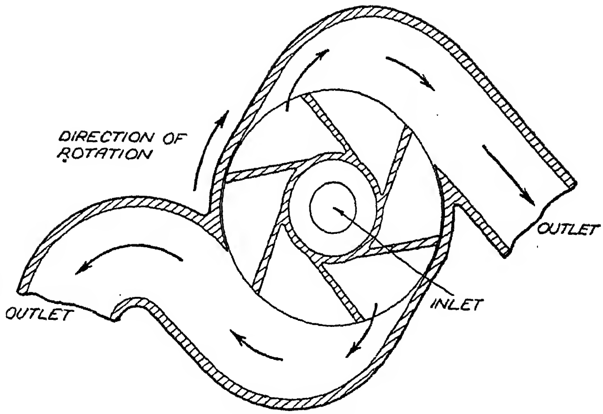


Fig. 28.—Liquid cooling pump.

Superchargers

The purpose of a supercharger on aero engines is to prevent, as far as possible, the falling off in power as height is gained and the density of the air decreases. The supercharger forces a greater weight of charge into the cylinder than would be induced by normal intake under the reduced pressure at altitude; the volume of each charge, of course, remains the same. The supercharger generally used on aero engines is a positive-driven centrifugal type. It consists of an impeller in a suitable casing, and is similar in construction to a liquid circulating pump. A supercharger is normally fitted between the carburetter and the induction chambers. The impeller is driven at high speed by suitable gearing from the crankshaft. The mixture of fuel and air entering the centre of the impeller is thrown outwards by centrifugal force into diffuser vanes at high velocity. These vanes reduce the velocity of the mixture and increase the pressure with which it enters the induction manifold.

Carburetters

A carburetter is an apparatus for vapourising and mixing the fuel with air in the correct proportions to form a combustible mixture. The simplest possible carburetter consists of two main parts, a float chamber and a jet.

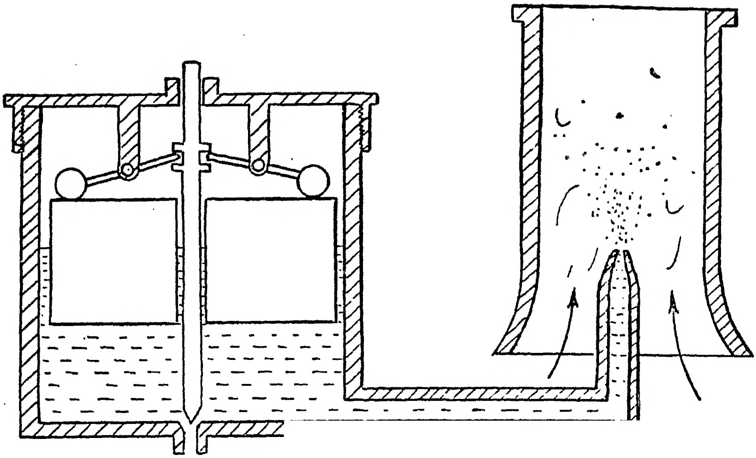


Fig. 29.—SIMPLE CARBURETTER.

Float Chamber

A float chamber, with its float mechanism, maintains a constant level of fuel in the jet, both for starting and for furnishing a constant supply at all times. When the fuel reaches a predetermined level in the float chamber the float cuts off the supply automatically by shutting a needle valve. The mechanism varies but in most carburetters the needle valve is actuated by a hollow metal or cork float.

Jet Assembly

A simple single-jet carburetter is suitable for an engine running at a specific speed, but is unsuitable for a variable speed engine, because the fuel supply increases more rapidly than the flow of air as the engine speed is increased and the mixture thus becomes richer and richer. By employing multiple jets the mixture strength can be kept constant at varying engine speeds. This is accomplished by many methods which are described in other articles.

Venturi Tube

A venturi tube is incorporated in all carburetters to lower the pressure, that is to say, produce a suction above the jet and to assist in atomising and mixing the fuel and air. A venturi tube is shown in Fig. 31, the narrow end being near the jet. As the same quantity of air must pass through the narrow part as through the wide part, it must move faster and will, therefore, be capable of picking up more fuel. The inside edges of the venturi tube are rounded and smooth in order to minimise the resistance to the air flow.

Throttle Valve

A throttle valve is incorporated in a carburetter to regulate the

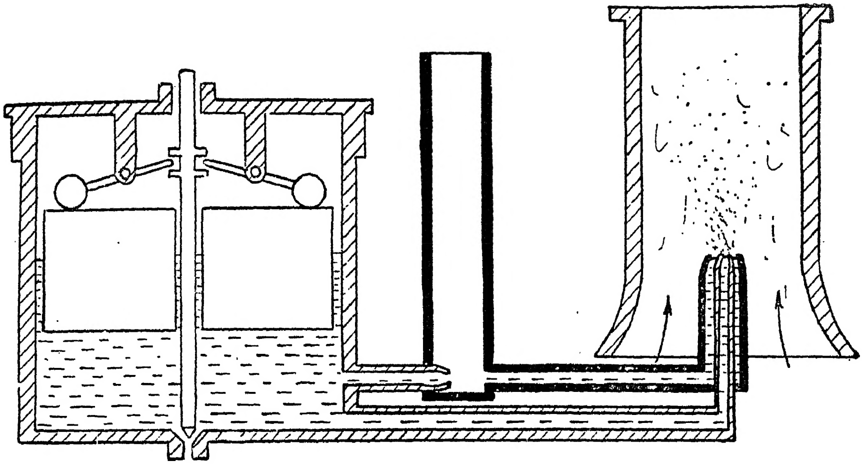


Fig. 30.—MULTIPLE JET CARBURETTER.

flow of the mixture to the induction manifold. This enables the engine speed and power to be regulated. The throttle valve may be of the butterfly valve or of a rotating barrel type. This valve must be simple in construction to minimise resistance to the flow of mixture, heavy enough to withstand buckling from back firing and be positive in action. An independent jet system should be incorporated to supply the mixture required for starting the engine, for slow running and for gliding.

Mixture Control

Mixture control is important in aero engines, and a device must be incorporated which can be, or is, automatically controlled in flight. This control must prevent the mixture becoming too rich at high altitudes due to the density of the air decreasing. The mixture control decreases the fuel supply in relation to the air, as an increase in the volume of air to keep the mixture correct can only be obtained by a supercharger. There are various methods of controlling the proportions of the mixture, but the three most generally used are as follows :—

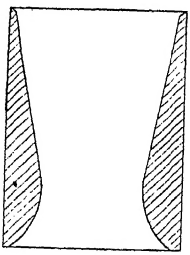


Fig. 31.—VENTURI TUBE.

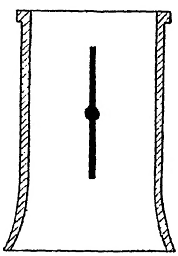


Fig. 32.—THROTTLE VALVE SHOWN OPEN.

(*a*) A fuel-regulating valve under the pilot's control is fitted in the supply duct from the float chamber to the jet, thus enabling the pilot to control the flow of fuel to the jet.

(*b*) An air duct, which can be opened or closed by a valve under the pilot's control, is led into the mixing chamber above the jet.

The depression or suction on the jet is decreased when this valve is opened and consequently the flow of fuel through t jet is reduced accordingly.

(c) The air pressure in the float chamber is reduced by making an a duct between the air-tight float chamber and the mixi chamber above the jet, with a valve to open or close it. Wh the air duct is open the pressure in the mixing chamber is equ lised with that in the float chamber, thus lowering the amount fuel drawn through to the jet.

Details of these methods are explained in Vol. I., p. 95.

Magnetos

A high-tension magneto is really a complete ignition system itse as it performs the necessary function of producing an electric spark without the aid of an outside source. The essential parts of a magneto are a magnet, an armature, a contact breaker and a distributor. No electricity is generated when the armature is stationary, that is to say, when the engine is not running, the magneto only possesses magnetism. The two most common types of magnetos are the rotating armature typ and the polar inductor type. These types differ in mechanical constructio but their electro-magnetic properties are similar.

The magnetism in all magnetos is supplied by permanent magnet The armature has a soft iron, laminated core, around which are wou the primary and secondary coils or windings. The primary coil consi of a few turns of comparatively thick wire and the secondary coil consi of many turns of fine wire. When the armature is revolved at high spe between the poles of the permanent magnet the wires of the primary c cut the " lines of magnetic force " with great rapidity and an elect current is induced in them.

Primary Circuit

For maximum efficiency the wires of the primary circuit should c the magnetic lines of force at right angles, and where there are most them, that is across the poles of the magnet. They should cut the lin of force as rapidly as possible and the primary wire cutting the magnet lines of force should be as long as possible. As the current of electricit produced in the primary coil of wire possesses little pressure or electr motive force (E.M.F.) it cannot overcome any great resistance. A muc greater E.M.F. can, however, be obtained by the use of a second coil c fine wire.

The *contact breaker* is a mechanism which is fitted to one end of th armature spindle to stop and start the induced current in the primar circuit. It consists of a rocker arm timed to make and break contac when the current in the primary circuit is at its maximum value The lines of force are, as it were, dragged round by the armature